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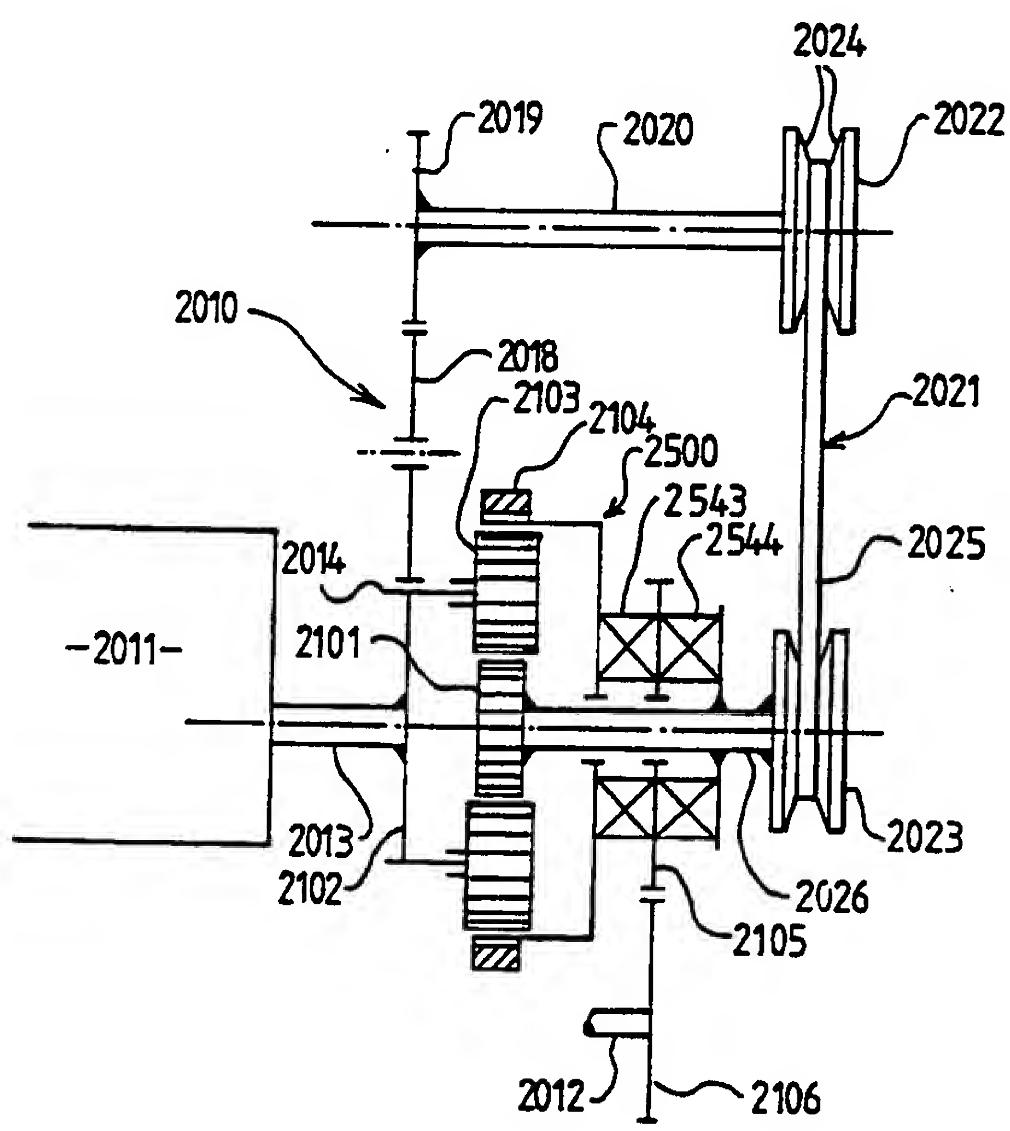
(54) Title: DRIVE TRANSMISSION

(57) Abstract

A drive transmission (2010) comprising a finite continuously variable transmission (FVT) (2021) having an input element (2020) and an output element (2026) and in which the ratio of the rotational speed of the input element (2020) to that of the output element (2026) is continuously variable over a finite range and a controllable differential (CD) (2500) having first (2102), second (2104) and third (2101) elements and wherein the second element (2104) of the CD (2500) is connectable to an output member (2012) of the drive transmission (2010), the input element (2020) of the FVT (2021) and the first element (2102) of the CD (2500) are connected to an input member (2013) of the drive transmission (2010) and the output element (2026) of the FVT (2021) is connected to the third element (2021) of the CD (2500).



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Title: "Drive Transmission"

This invention relates to a drive transmission.

An object of the invention is to provide a new and improved drive transmission.

According to one aspect of the invention we provide a drive transmission comprising a finite continuously variable transmission (FVT) having a first element and a second element and in which the ratio of the rotational speed of the first element to that of the second element is continuously variable over a finite range and a controllable differential (CD) having first, second and third elements and wherein the second element of the CD is connectable to a first drive member of the drive transmission, the first element of the FVT and the first element of the CD are connected to a second drive member of the drive transmission and the second element of the FVT is connected to the third element of the CD.

The first and second elements of the FVT may comprise input and output members respectively. The first and third elements of the CD may comprise first and second input members whilst the second element comprises an output member.

The first drive member of the drive transmission may comprise an output member and the second drive member of the drive transmission may comprise an input member.

It has been proposed to use a hydrostatic transmission as an infinitely variable transmission to provide a variable speed input to a differential gear set acting as a dual mode or power split infinitely variable transmission whilst a prime mover provides a constant speed input to the hydrostatic transmission and a constant input to the differential gear set.

For a multi-range differential gear set providing a dual mode or power split infinitely variable transmission, i.e. a transmission in which the ratio of input speed to output speed is infinite due to the output speed being zero, it is preferred to provide a variable speed input which is rotatable in either a forward

direction or in a reverse direction as well as at zero speed and which has the same forward and reverse speed ranges. This is required firstly to make it possible to provide a continuous speed variation between forward and reverse without having to use conventional friction clutches, and secondly to alternate the variable input speed to the differential gear set through zero as the multi-range differential gear set goes through its ranges, with the extreme forward and reverse speeds of the variable speed input being reached at synchronisation and change points of the multi-range transmission.

It is preferred that the variable speed transmission which provides the variable speed input should at least have constant torque capacity throughout its range, and, preferably, higher torques close to zero speeds. These requirements have hitherto been generally met by using a hydrostatic variable speed transmission to provide the variable speed input to the differential gear set.

Hydrostatic transmissions, however, are, costly, inefficient, especially at zero and maximum speeds, and noisy, especially if used at their limits. For this reason hydrostatic drives have not been generally used for automotive purposes.

Mechanical continuously variable transmissions do not suffer from these disadvantages.

However, mechanical continuously variable transmissions have the disadvantage of only having a single direction of rotation, nor can they provide an output speed close to zero. Hence they provide a finite continuously variable transmission (FVT).

According to a first more specific aspect of the invention the drive transmission may include an intermediate controllable differential (ICD) having first, second and third elements and wherein the first element of the ICD is connected to said second drive member, the third element of the ICD is connected to the second element of the FVT and the second element of the ICD is connected to the third element of the CD.

The first and third elements of the ICD may comprise first and second input elements thereof whilst the second element of the ICD may comprise an output element.

The invention according to the first more specific aspect enables a finite continuously variable transmission (FVT), for example a mechanical constant velocity transmission, to be used with a controllable differential to provide an infinitely variable transmission.

The invention is particularly suitable if for any given vehicle

1. the speed range of the FVT is not sufficiently high;
2. it is required to have a high driving torque around zero speed;
3. it is required to have a wide reversing range;
4. it is required to shuttle backwards and forwards;
5. the power capacity of the FVT is too low, a considerable power extension is possible by virtue of coupling the FVT to a multi-range controllable differential.

The CD may comprise any suitable differential gear.

For example, the CD may comprise a parallel axis epicyclic gear set.

By a "parallel axis epicyclic gear set" we mean a gear set comprising an annulus, acting as a first element, a planet carrier, acting as a second element, supporting planet gears which are rotatable about axes parallel to the first element and in mesh with the annulus, and a sun gear, acting as a third element, in mesh with the planet gears.

Alternatively the CD may comprise a cross axis epicyclic gear set.

By a "cross axis epicyclic gear set" we mean a gear set comprising a first bevel gear, acting as a first element, a planet carrier, acting as a second element, supporting planet gears which are rotatable about axes transverse to the first element and in mesh with the first bevel gear, and a second bevel gear, acting as a third element, in mesh with the planet gears. The axes of rotation of the planet gears may be radial to the first element or inclined to a radius, for example, where the bevel gears are of different size.

Alternatively, the CD may comprise a "sun wheel compound parallel axis epicyclic gear set"

By a "sun wheel compound parallel axis epicyclic gear set" we mean a gear set comprising an annulus, acting as a first element, a planet carrier, acting as a second element, supporting pairs of intermeshed planet gears which are rotatable about axes parallel to the first element and one planet gear of each pair of planet gears being in mesh with the annulus and a sun gear, acting as a third element, and in mesh with the other planet gear of each pair of planet gears.

Alternatively, the CD may comprise a "twin annulus compound parallel axis epicyclic gear set".

By a "twin annulus compound parallel axis epicyclic gear set" we mean a gear set comprising a first annulus, acting as a first element, a planet carrier, acting as a second element, supporting pairs of intermeshed planet gears which are rotatable about axes parallel to the first element and one planet gear of each pair of planet gears being in mesh with the first annulus and a second annulus, acting as a third element, and in mesh with the other planet gear of each pair of planet gears.

Alternatively, the CD may comprise a "spur gear epicyclic gear set".

By a "spur gear epicyclic gear set" we mean a gear set comprising a first spur gear, acting as a first element, a planet carrier, acting as a second element, supporting pairs of planet gears, the gears of each pair being intermeshed and one gear of each pair being in mesh with the first spur gear and a second spur gear, acting as a third element, in mesh with the other gear of each pair of planet gears.

Alternatively, the CD may comprise an "annulus and twin sun gear epicyclic gear set".

By "annulus and twin sun gear epicyclic gear set" we mean
a gear set comprising,
a carrier, acting as a first element,
a plurality of first planet gears,
a plurality of second planet gears,
the carrier supporting the first and the second planet gears,

an annulus acting as a second element,

a first sun gear, acting as a third element, in mesh with the first planet gears,

each second planet gear being in mesh with a first planet gear and with the annulus, and

a second sun gear, acting as a fourth element, in mesh with the second planet gear.

The second and fourth elements may be alternately connectable to a first drive member of the transmission.

The first and third elements may be connectable to second and third drive members of the transmission respectively.

The first drive member may be a driven member and the second and third drive members may be driving members.

Alternatively the first drive member may be a driving member and the second and third members driven members.

The first planet gears may be disposed closer to the first sun gear than the second planet gears.

The first and second planet gears may be mounted for rotation about respective axes which lie in a common plane radial to the axis of rotation of the carrier.

Alternatively the first and second planet gears may be mounted for rotation about axes which lie in different planes radial to the axis of rotation of the carrier.

By supporting the first and second planetary gears on the planet carrier a relatively wide range of ratios is available.

A still greater range of ratios is made available by virtue of the following features.

The first planet gears and/or the second planet gears may have meshing parts of different diameter.

Each first planet gear may have a first meshing part in mesh with the first sun gear and a second meshing part in mesh with a second planet gear, the first and second meshing parts being of different diameter.

Preferably the first meshing part is of greater diameter than the second meshing part but if desired the first meshing part may be of smaller diameter than the second meshing part.

Alternatively, or in addition, each second planet gear may have a first meshing part in mesh with the first planet gear, a second meshing part in mesh with the annulus and a third meshing part in mesh with the second sun gear and at least one of said meshing parts may be of a different diameter to the other meshing part or parts.

In one preferred embodiment, however, the second planet gear is of constant diameter and of the same diameter as the first sun gear.

The first, second, third and fourth elements of the transmission may be rotatable about a common axis.

Preferably in this first more specific aspect of the invention the CD comprises a four-branch CD having a fourth element in addition to said first, second and third elements and said third and fourth elements being alternately connectable to the first drive member of the drive transmission.

The fourth element of the CD may comprise an output member.

The CD may be a controllable four branch differential gear and may comprise a first stage summing gear set and a second stage summing gear set.

The first stage summing gear set may comprise a "parallel axis epicyclic gear set" or a "spur gear epicyclic gear set".

The second stage summing gear set may comprise a "parallel axis epicyclic gear set" or a "cross axis epicyclic gear set" or a "sun wheel compound epicyclic gear set" or a "twin annulus compound parallel axis epicyclic gear set", or a "spur gear epicyclic gear set".

The third element of the second stage summing gear set may be connected to said output member of the variable speed transmission and may be

so connected so as to rotate in the same direction as the third element of the first stage summing gear set.

The second element of the second stage summing gear set may be connected to rotate with the first element of the first stage summing gear set.

A fourth clutch may be provided for connecting the second element of the first stage summing gear set to the driven member and a fifth clutch may be provided for connecting the second stage summing gear set to the driven member.

The first element of the second stage summing gear set may be connectable by said fifth clutch to the driven member.

Where the first stage summing gear set comprises a "spur gear epicyclic gear set" the first stage summing gear set may be provided with a third spur gear, acting as a fourth element, in mesh with one gear of each pair of planet gears and thus connected to rotate with the first element of the first stage summing gear set, with the second element of the second stage summing gear set being connected to rotate with the fourth element of the first stage summing gear set.

The second stage summing gear set may be disposed between the controllable four branch differential gear and the reversing gear set.

Alternatively, the second stage summing gear set may be disposed on the opposite side of the controllable four branch differential gear to the reversing gear set.

A range change gear set may be provided, there being a sixth clutch to connect the controllable four branch differential gear to the driven member through the range change gear set.

Where a second stage summing gear set is provided there may be a clutch to connect the first element of the second stage summing gear set to the driven member through the range change gear set.

The range change gear set may comprise an epicyclic gear set comprising a first member lockable relative to a fixed part of the transmission by an eighth clutch, a planet carrier acting as a second element and a third element.

The range change gear set may be a parallel axis epicyclic gear set or a cross-axis epicyclic gear set.

The third element of such epicyclic range change gear set may be connectable with the second element of the first stage summing gear set by the sixth clutch and with the first element of the second stage summing gear set, when provided, by the seventh clutch.

The second element of such epicyclic range change gear set may be connectable with the first element of the second stage summing gear set, when provided, by the fifth clutch and may also be connected to the driven member.

The ICD may comprise any suitable differential gear and may comprise, for example, a "parallel axis epicyclic gear set", a "cross-axis epicyclic gear set", a "sun wheel compound parallel axis epicyclic gear set", a "twin annulus compound parallel axis epicyclic gear set", but is preferably a "spur gear epicyclic gear set".

A reversing gear may be connectable between the output element of the intermediate CD and said first element of the differential gear.

The first, second and third elements of the range change gear set may all be rotatable about said second axis and the range change gear set may be disposed on the opposite side of the controllable four branch differential gear to the reversing gear set.

The reversing gear set may comprise a "cross axis epicyclic gear set", with equal sized first and second bevel gears which is particularly suitable because the gear ratio of the train is unity.

Alternatively the reversing gear set may comprise a "parallel axis epicyclic gear set".

Further alternatively, the reversing gear set may comprise a "sun wheel compound parallel axis epicyclic gear set" or a "twin annulus compound parallel axis epicyclic gear set".

Where the reversing gear set comprises a "cross axis epicyclic gear set", a "parallel axis epicyclic gear set" or a "twin annulus compound parallel axis

epicyclic gear set" the third element of the reversing gear set may be connectable by said second clutch to said output element of the variable speed transmission and may be so connected so as to rotate in the same direction as the third element of the controllable four branch differential gear.

The second element of the reversing gear set may be stationary.

The first element of the reversing gear set may be connected to rotate with the second element of the second stage summing gear set.

When the reversing gear set comprises a "sun gear compound parallel axis epicyclic gear set" the third element of the reversing gear set may be connectable by said second clutch to said output element of the variable speed transmission and may be so connected so as to rotate in the same direction as a third element of the controllable four branch differential gear.

The second element of the reversing gear set may be connected to rotate with the first element of the second stage summing gear set.

The first element of the reversing gear set may be stationary.

Where the reversing gear set is any one of the above mentioned kind of epicyclic gear set the third element of the reversing gear set may also rotate about said second axis of rotation of the controllable four branch differential gear, as may the first and second elements of the reversing gear set.

Further alternatively, the reversing gear may comprise a "spur gear lay shaft reversing gear set".

By a "spur gear lay shaft reversing gear set" we mean a gear set comprising a first spur gear in mesh with a second, idler spur gear which is in mesh with a third spur gear carried on a lay shaft and the spur gears being rotatable about parallel axes.

Where the reversing gear set comprises a "spur gear lay shaft gear set" the first spur gear may rotate about said second axis of rotation and the lay shaft may rotate about the first axis of rotation.

In a second more specific aspect of the invention the second element of the FVT is connected to the third element of the CD by a direct drive

connecting means and the second element of the CD and the second element of the FVT are alternately connectable to said first drive member of the drive transmission.

In the second more specific aspect of the invention, i.e. where the transmission does not include an ICD, the CD may comprise any suitable three-branch differential gear such as a "parallel axis epicycle gear set", a "cross-axis epicyclic gear set", a "sun wheel compound parallel axis epicyclic gear set", a "twin annulus compound parallel axis epicyclic gear set", or a "spur gear epicyclic gear set".

In a third more specific aspect of the invention the second element of the FVT is connected to the third element of the CD by a direct drive connecting means and the CD has a fourth element and the third and fourth elements are alternately connectable to the first drive member of the drive transmission.

In the third more specific aspect of the invention, i.e. where the transmission does not include an ICD and the CD is a four-branch differential gear, the CD may comprise any suitable four-branch differential which may comprise a first stage summing gear set and a second stage summing gear set and the first stage summing gear set may comprise a "parallel axis epicyclic gear set" or a "spur gear epicyclic gear set", whilst the second stage may comprise a "parallel axis epicyclic gear set" or a "cross-axis epicyclic gear set" or a "sun wheel compound epicyclic gear set" or a "twin annulus compound epicyclic gear set" or a "spur gear epicyclic gear set". Alternatively the four-branch CD may comprise an "annulus, single planet and twin sun gear epicyclic gear set".

By "annulus, single planet and twin sun gear epicyclic gear set" we mean a gear set comprising

a carrier, acting as a first element,

a plurality of planet gears,

a carrier supporting said planet gears,

an annulus acting as a second element, and in mesh with the planet gears,

a first sun gear, acting as a third element, in mesh with the planet gears, and

a second sun gear, acting as a fourth element, in mesh with the planet gears.

The planet gears may have meshing parts of different diameters and may have a first meshing part in mesh with the first sun gear and a second meshing part in mesh with the annulus and the second sun gear, the first and second meshing parts being of different diameter.

In this case, the first meshing part is of greater diameter than the second meshing part but, if desired, the first meshing part may be of smaller diameter than the second meshing part.

In the first more specific aspect of the invention a finite constant velocity transmission (FVT) such as a mechanical CVT directly replaces a hydrostatic variable speed transmission as a variable speed input to a differential gear set by converting the single direction output of a finite FVT into a forward/reverse output by means of an intermediate differential.

This transmission is particularly suitable for use in vehicles where high torques at low speeds and forward and reverse shuttling are required, for example in wheeled loaders and back hoe loaders.

However, where, as in most other types of vehicle, reversing of the vehicle plays a minor role, i.e. reverse speeds are relatively low as in a car, lorry, tractor etc., then, according to the second and third more specific aspects of the invention an FVT such as a mechanical CVT is coupled directly to an input of a controllable three or four branch differential.

The ratios of the differential are chosen in such a way that either the requirement for a wide speed range, or low power recirculation can be met, i.e. for a fast high powered car $R0_2$ would be relatively high to avoid high power being transmitted by the FVT. The speed range may be extended by having many ranges within the controllable differential.

Alternatively, a small tractor with relatively low power may have a low $R0_2$ in only two ranges, whereby the power for the FVT could be the same or even higher than the prime mover power, especially if the multi-range

transmission is also required to drive the vehicle close to zero speed or in slow reverse.

This transmission will therefore extend the range of any mechanical or other single direction or finite continuously variable transmission in terms of speed and/or torque as required.

The use of stepped planet gears in the controllable differential makes it possible to achieve more and higher ratios.

By a direct drive connecting means we mean a drive connecting means the output speed of which varies in dependence upon only the speed of rotation of the second element of the FVT and not in dependence on the speed of rotation of the second drive member of the drive transmission. That is say, the direct drive connecting means does not comprise a differential gear having an input from the second drive member of the drive transmission as well as from the second drive member of the FVT.

In the transmission shown in Figure 3 hereof unequal output ratios (upper ρ and lower ρ) are obtained. However, there is a version where these ratios are equal (when $\rho_F = R_{02}$ and $R_{01} = R_{02} + \rho_F$) and the resulting ρ out becomes 2.

With this ratio and with the assumptions explained hereinafter in relation to Figure 3, maximum power recirculation will equal engine power. As this power recirculation is generally too high, larger R_{02}'s are required and therefore upper and lower ρ out becomes unequal.

A further object of the present invention is to provide a drive transmission which overcomes or reduces these disadvantages and which aims to equalise the two output ratios whilst providing an acceptable power recirculation.

This further object is achieved by providing a transmission according to the third more specific aspect of the invention in which the CD comprises a controllable differential according to the second or the third aspect of the invention.

The FVT may be a mechanical continuously variable transmission such as a split pulley type finite continuously variable transmission comprising a pair of split pulleys having variable spacing cheeks, drivingly interconnected by a

continuous loop and in which the radius at which the loop drivingly engages the split pulleys is continuously adjustable by varying the spacing between the cheeks of the split pulleys. Preferably the loop is a metal pusher belt.

Alternatively the mechanical continuous variable transmission may be of the toroidal disk drive type comprising two disks each with a toroidal working surface engageable by a roller, the axis of rotation of the roller being adjustable to vary the radial positions at which the roller engages the toroidal surfaces.

According to a second aspect of the present invention we provide a controllable differential, comprising

a carrier, acting as a first element,

a plurality of planet gears, each planet gear having first, second and third meshing parts of different diameter,

the carrier supporting the planet gears,

an annulus, acting as a second element, in mesh with said first meshing part,

a first sun gear, acting as a third element, in mesh with said second meshing part, and

a second sun gear acting as a fourth element in mesh with said third meshing part.

The second meshing part may be of greatest diameter and the third meshing part of smallest diameter.

The first meshing part may be disposed between the second and third meshing parts.

The fourth element may comprise a hollow shaft surrounding the third element and disposed within the second element, said second, third and fourth elements may be coaxial and extend from one side of the gear set, whilst the first element may extend from the opposite side of the gear set coaxial with said second, third and fourth elements.

According to a third aspect of the present invention we provide a controllable differential, comprising

a carrier, acting as a first element,

a plurality of first planet gears, each first planet gear having first and second meshing parts of different diameter,

a plurality of second planet gears,

the carrier supporting the planet gears,

a first sun gear, acting as a second element in mesh with the second planet gears,

a second sun gear, acting as a third element, in mesh with said first meshing part of the first planet gears,

a third sun gear, acting as a fourth element, in mesh with said second meshing part of the first planet gears, and

said second meshing part of the first planet gears being in mesh with a respective second planet gear.

The first meshing part may be of larger diameter than the second meshing part.

The fourth element may comprise a hollow shaft coaxial with said first element and disposed within said second element.

The second, third and fourth elements may be coaxial and project from one side of the transmission whilst the first element may project on the opposite side of the transmission coaxial with said second, third and fourth elements.

Four examples of the invention will now be described with reference to the accompanying drawings wherein:

FIGURE 1 is a diagrammatic illustration of a drive transmission embodying the invention,

FIGURE 2 is a diagrammatic illustration of an alternative embodiment of a drive transmission embodying the invention,

FIGURE 3 is a diagrammatic illustration of another drive transmission embodying the invention, and

FIGURE 4 is a diagrammatic illustration, in section on the line 4-4 of Figure 5, of an epicyclic gear set used in the transmission of Figure 1,

FIGURE 5 is a fragmentary end view of the gear set shown in Figure 4,

FIGURE 5a is a fragmentary end view of a modification of the gear set shown in Figure 5,

FIGURE 6 is a diagrammatic illustration similar to that of Figure 4 but of an alternative embodiment of the gear set and on the line 6-6 of Figure 7,

FIGURE 7 is a fragmentary end view of the gear set shown in Figure 6,

FIGURE 7a is a fragmentary end view of a modification of the gear set shown in Figure 6,

FIGURE 8 is a diagrammatic illustration similar to that of Figure 4 but of an alternative embodiment of the gear set and on the line 8-8 of Figure 9,

FIGURE 9 is a fragmentary end view of the gear set shown in Figure 8,

FIGURE 10 is a diagrammatic illustration of an alternative differential gear set,

FIGURE 11 is a diagrammatic illustration of another alternative differential gear set,

FIGURE 12 is a diagrammatic illustration of another alternative differential gear set,

FIGURE 13 is a diagrammatic illustration of another alternative differential gear set,

FIGURE 14 is a diagrammatic illustration of another alternative differential gear set,

Figure 15 is a diagrammatic illustration of a 2-range drive transmission embodying the invention;

Figure 16 is a diagrammatic illustration of a controllable differential for use in the transmission of Figure 15;

Figure 17 is a section on the line 17-17 of Figure 16;

Figure 18 is a diagrammatic illustration of an alternative form of controllable differential used in the transmission of Figure 15;

Figure 19 is a section on the line 19-19 of Figure 18;

Figure 20 is a diagrammatic illustration of a 4-range drive transmission embodying the invention;

Figure 21 is a diagrammatic illustration of an alternative FVT;

Figure 22 is a diagrammatic side view of a construction vehicle embodying the invention, and

Figure 23 is a diagrammatic plan view showing the drive transmission of the vehicle of Figure 22.

Referring to Figure 1, a drive transmission 1010 is provided to connect a prime mover, such as a diesel engine 1011, of a vehicle, such as a construction vehicle, such as a front end loader, to the driving wheels thereof by a drive shaft 1012 comprising a first drive member of the drive transmission.

The transmission 1010 has an input member 1013 comprising a second drive member of the drive transmission and which is driven by the prime mover 1011.

The input member 1013 carries a gear 1014 which meshes with a further gear 529 which is connected by a first clutch 528 to a planet carrier 530 of a controllable four branch differential gear 500 (CD), hereinafter to be described in more detail.

The gear 1014 meshes with a gear 1015 connected to an input shaft 1016 of a three branch intermediate differential gear set 1017 (ICD) of the "spur gear epicyclic gear set" type. The gear 1015 meshes with an idler gear 1018 which meshes with a gear 1019 connected to an input element 1020 of a split pulley type finite continuously variable transmission (FVT) 1021.

The FVT 1021 is of conventional type comprising a pair of split pulleys 1022, 1023 having variably separable cheeks 1024 which together define a frusto conical recess of variable width in which a continuous loop member 1025 is drivingly received. By varying the spacing between the cheeks 1024 the radius at

which the belt 1025 engages the pulleys 1022, 1023 can be varied thereby varying the ratio of the speed of rotation of the output pulley 1022 on the input pulley 1022. It is preferred that the loop 1025 is a metal, such as steel, pusher belt.

The mechanical continuously variable transmission 1021 may be of other kind such as a toroidal disc type drive comprising two discs each with a toroidal working surface engaged by a roller, the axis of rotation of the roller being adjustable to vary the radial positions at which the roller engages the toroidal surfaces thereby to adjust the relative rates of rotation of the two discs.

All such mechanical continuous variable transmissions have a finite ratio of input speed to output speed since the output speed can never reach zero.

The output member or pulley 1023 of the FVT 1021 is connected to a shaft 1026 which is connected to a first sun gear 1027 of the three branch differential gear 1017. The differential gear 1017 has a plurality of pairs 1028 of intermeshed planetary gears 1028a,b which are carried on a planet carrier 1029 fixed to the shaft 1016. The planet gears 1028a mesh with the sun gear 1027 whilst the planet gears 1028b mesh with a second sun gear 1029 which meshes with a further gear 1030 connected to a shaft 1031 which is connected by a second clutch 558 to a gear 557 which meshes with an idler gear 556 which meshes with a gear 555 provided on the carrier 530.

The carrier 1029, the second sun gear 1029 and the first sun gear 1027 respectively provide first, second and third elements of the three branch differential 1017.

The three branch differential 1017 thus provides an intermediate controllable three branch differential (CD) disposed between the output pulley 1023 of the finite continuously variable transmission (FVT) 1021 and an input, hereinafter to be described, to the four branch controllable differential 500 (CD).

Referring now particularly to Figures 4-5a, the planet carrier 530 of the controllable four branch differential (CD) 500 carries, in the present example, two first planet gears 531 and two second planet gears 532. These gears are mounted, in conventional manner, on shafts 533 fixed to the carrier 530. The first

pinions 531 have a first meshing part 534 and a second meshing part 535 of smaller diameter than the first meshing part 534. The planet gears 532 are of constant diameter.

The first meshing part 534 of the first planet gears 531 mesh with a first, spur, sun gear 536 fixed to a shaft 537 which comprises a third driven member. The gear 529, planet carrier 530 and shaft 537 rotate about an axis Y-Y which is parallel to and spaced from the axis X-X described hereinbefore. The shaft 537 extends through the controllable four branch differential gear and carries, at the end thereof opposite that carrying the sun gear 536, a spur gear 538 which meshes with the gear 1030 fixed to the shaft 1031.

The second meshing parts 535 of the first planet gears 531 mesh with a portion of the second planet gears 532. A longitudinally adjacent portion of the surface of the second planet gears 532 meshes with a second, spur, sun gear 539, also mounted for rotation about the axis Y-Y.

The second planet gears 532 are also in mesh with an annulus 540 mounted to rotate about the axis Y-Y.

The carrier 530 acts as a first element of the controllable four branch differential gear 500 whilst the annulus 540 acts as a second element, the first sun gear 536 acts as a third element and the second sun gear 539 acts as a fourth element.

The second element 540 and the fourth element 539 of the controllable four branch differential gear 500 are alternately connectable to the first drive member 1012 by clutches, hereinafter to be described.

The annulus 540 is connected to a gear 541 which meshes with the gear 542 connectable by a clutch, hereinafter referred to as a fourth clutch 543, to the first drive member 1012. The gear 541 is alternately connectable by a fifth clutch 544 to a further gear 545 which meshes with a gear 546 rotatable about the same axis as the first drive member 1012 and which is connected to a sun gear 547 of a further epicyclic gear train 548 having a plurality of planet gears 549 which mesh with the sun gear 547 and with a fixed annulus 550. The planet gears

549 are carried by a planet carrier 551 which is connected to the member 1012 so that rotation of the gear 546 by the gear 545 is transmitted to the member 1012 through the epicyclic gear set 548 as a result of rotation of the planet carrier 551.

The fourth element of the controllable four branch differential gear 500 provided by the second sun gear 539, is connectable by a sixth clutch 552 to the gear 545.

The planet carrier 530 of the controllable four branch differential gear 500 is provided with a gear 555 which meshes with the idler gear 556 which meshes with the gear 557 which is connectable by the second clutch 558, to the shaft 1031. The shaft 1031 is also connectable by a clutch, hereinafter referred to as a third clutch 559, to the gear 1014 and hence to the input member 1013.

Figure 5a shows an alternative configuration of the planet gears where, unlike Figure 5, the planet gears are not rotatable about axes lying in a common plane radial to the axis of rotation of the carrier.

In use, assuming that the vehicle is stationary so that the driving shaft 1012 is stationary, the first and third clutches 528 and 559 are disengaged whilst the second clutch 558 is engaged, the fifth clutch 544 is engaged and the fourth and sixth clutches 553 and 552 are disengaged. The engine 1011 rotates the input member 1013 which via the gears 1014, 1015, 1018 and 1019, rotates the input element 1020 of the FVT 1021. Also the gear 1015 and shaft 1016 rotates the first element, i.e. planet carrier 1029 of the ICD 1017.

At this stage, the FVT is arranged so that its output is in the middle of its range and the gearing of the ICD is such that under these conditions there is no rotation of the second element 1029 and thus there is no rotation of the shaft 1031 and hence no rotation or input into the CD 500 in view of the disengagement of the first clutch 528 and the engagement of the second clutch 558.

By altering the ratio of the FVT in the appropriate direction the ICD is caused to provide a variable speed of rotation of the second element 1029

preferably in the same direction as the direction of rotation of the output pulley 1023 to rotate the gear 1030 and thus rotate the shaft 1031. The shaft 1031 causes the gear 557 to rotate and thus to rotate the gear 555 in the same direction because of the interposition of the idler gear 556. In consequence, the planet carrier 530 is rotated in the same direction as the shaft 1031. At the same time, the gear 1030 drives the gear 538 and thus the shaft 537 and hence the first sun gear 536 is rotated in the opposite direction to the planet carrier 530. Consequently annulus 540, which constitutes the second element of the gear 500, is caused to rotate in the opposite direction to the direction of rotation of the third element 536 thereof. This forward motion of the second element 540 is transmitted by the fifth clutch 544 to the gear 545 which drives the first drive member 1012 through the epicyclic gear train 548. As the FVT is adjusted further the speed of rotation of the gear 1028 increases, with the corresponding decrease in torque. The transmission provides a maximum torque when the vehicle is starting to move away from stationary.

At near maximum adjustment of the FVT the gear 1029 of the ICD is rotating at the same speed as the planet carrier 530. Hence, at this stage the speed of rotation of the gear 529 is synchronous with the speed of rotation of gear 555 driven from the gear 557 and so the first clutch 528 may be engaged and, indeed, the first and second clutches 528, 558 may be simultaneously engaged so that drive is constantly transmitted.

Once the first clutch 528 has been engaged the output speed of the FVT may be adjusted and, shortly after, the second clutch 558 will automatically be disengaged. With further adjustment in the speed of the output element 1023 of the FVT slows and hence of the gear 1029 and the speed of rotation of the first sun gear 536 of the controllable four branch differential gear 500 also slows, whilst the first element of the gear 500 provided by the carrier 530 is continued to be rotated at engine speed. The slower rate of rotation of the sun gear 536 compared with the rate of rotation of the first element 530 causes faster rotation

of the second element 540 and thus continued faster rotation of the output member 512.

When the FVT has been adjusted so that the gear 1029 is again stationary the sun gear 536 is stationary whilst the carrier 530 continues to rotate at the same speed provided by the prime mover 1011 so the second element 540 continues to rotate faster.

As the FVT is adjusted further the sun gear 526 rotates in the reverse direction at an increasing rate whilst the carrier 530 continues to rotate at a constant rate, thus further increasing the rate of rotation of the second element 540. At this stage the fifth clutch 544 is disengaged and the sixth clutch 552 is engaged so that drive is now transmitted through the fourth element, i.e. the second sun gear 539, and the sixth clutch 552 to the gear 545 and then via the epicyclic transmission 548 to the drive shaft 1012.

If desired, the fifth and sixth clutches may be simultaneously engaged for a period of time during changeover to avoid any interruption of the drive transmission because of the synchronicity of speeds of the annulus 540 and the second sun gear 539.

On adjusting the FVT again towards its mid output position the speed of rotation of the output member 1029 of the ICD is decreased, thus decreasing the speed of the sun gear 536, whilst the carrier 530 continues to rotate at constant speed and thus the sun gear 539 is caused to rotate at a greater speed which is transmitted via the sixth clutch 552 to the drive member 1012.

As the FVT is adjusted beyond its mid position the output element 1029 rotates in the opposite direction at an increasing speed, thus rotating the sun gear 536 at increasing speed in the opposite direction, whilst the carrier 530 is rotated at the same speed, thus causing still faster rotation of the second sun gear 539 and hence of the member 1012.

When the FVT has been adjusted in said opposite direction to its maximum value, the fourth clutch 543 is engaged and the sixth clutch 552 disengaged so that the annulus 540 again transmits drive but in this case through

the gear 541 to the gear 542 which is connected by the fourth clutch 543 to the drive member 1012 so that on reversal of the direction of adjustment of the FVT, the drive shaft 1012 is driven at increasing speed.

When it is desired to drive the vehicle in a reverse direction, initially, the FVT is adjusted in the opposite direction to that described hereinbefore for forward drive so that the output element 1029 is rotated in the reverse direction and hence drive again takes place similar to that described hereinbefore but in the reverse direction. When the FVT has been adjusted so that the output element 522 is rotating at the same speed as the input element 518 but in the reverse direction, the second clutch 558 is disengaged and the third clutch 559 is engaged, the first clutch 528 remaining disengaged. Again, the second and third clutches 558 and 559 may be simultaneously engaged during changeover.

As the FVT is adjusted towards its mid range point, the annulus 540 is driven in the reverse direction to that previously described, by virtue of its being driven via the carrier 530 and the first sun gear 536 but in the opposite direction to that in which it was driven to the idler gear 556. Otherwise, the transmission operates in an exactly similar manner, but in the reverse direction, to that described hereinbefore for forward drive. The hereinbefore described transmission therefore provides forward or reverse drive up to the same maximum speed through a "solely FVT" range and three compound ranges thus providing a maximum torque at zero vehicle speed as the vehicle starts to move in either forward or reverse.

The hereinbefore described gear set illustrated in Figures 4 - 5a provides a wide range of ratios.

If, however, a smaller range of ratios is acceptable, an alternative epicyclic gear set may be provided instead of the controllable four branch differential gear 500 shown in Figures 4 - 5a.

Referring now to Figures 6 - 7a, such an alternative form of controllable four branch differential gear is illustrated at 600. In Figures 6 - 7a the same reference numerals have been used to refer to corresponding parts as

were used in Figures 4 - 5a but with the substitution of an initial figure 6 for figure 5.

The controllable four branch differential gear 600 differs from the gear 500 solely by virtue of the first planet gears 631 being of constant diameter instead of the stepped configuration of the gear 500. The absence of stepping limits the ratios available.

Figures 8 and 9 show a further alternative configuration of controllable four element differential gear referred to as 700 in Figures 8 and 9. The same reference numerals have been used in Figures 8 and 9 as were used in Figures 4 - 5a for corresponding parts but with the substitution of an initial figure 7 for a figure 5. The gear set shown in Figures 8 and 9 differs from the gear sets previously described and in particular from the gear set of Figures 4 - 5a by virtue of the first planet gears 731 not being supported on the carrier 630. Instead, the first planet gears 731 "float". That is to say, each first planet gear 731 is retained in mesh with two adjacent second planet gears 732 and with the first sun gear 736 solely by virtue of its meshing therewith, as best shown in Figure 9.

This configuration of gear set provides still more limited ratios than the gear sets described hereinbefore.

Although the controllable four branch differential gears 500 - 700 and associated transmission have been described hereinbefore in one particular application, they may be used in other applications and, in particular, the controllable four branch differential gears 500, 600, 700 may be used in applications where the first drive member, i.e. the member to which the annulus 540, 640, 740 and the second sun gear 539, 639, 739 may alternately be connected is either a driven shaft, as in the previously described embodiment, or a driving shaft, whilst the second element 529, 629, 729 and the third element 537, 637, 737 may comprise driven shafts instead of driving shafts of the previously described embodiment.

A transmission embodying the invention and as described with reference to Figure 1 may be described mathematically by applying the following rules.

1 .

The prime mover input speed into the intermediate differential shall be at prime mover r.p.m. (n Eng)

2 .

The intermediate differential output speed shall also be at a maximum of prime mover r.p.m.

3 .

The FVT lower output speed shall be at prime mover r.p.m.

4 .

ρ_F = speed range of FVT

5 .

Ro = differential gear ratio,

i.e. FVT input speed: intermediate differential output speed.

Different assumptions may be made with the transmission still functioning as required, e.g. the capacity may be increased by increasing its speed. However, ratios on input or output or alternatively Ro would then have to change accordingly.

With the assumptions set out in 1 to 5 above, it follows that the FVT input speed, which is also the mid range speed of its output, is:

$$NV_{in} = NV_{mid} = \sqrt{\rho_F}$$

and maximum ICD output speed is:

$$NV_{max} = N_{Eng} \times \rho_F$$

The minimum torque capacity of the FVT will be at the extreme speed output and the mid range torque will be:

$$T_{mid} = T_{min} \times \sqrt[4]{\rho_F}$$

The relationship between the differential gear ratio and the FVT speed range is:

$$Ro = \frac{2}{\rho_F - 1}$$

Power recirculation is most likely to occur at zero output speed from the ICD where theoretically no power is required on prime mover input but input and output torques could be infinitely high.

The capacity of the transmission can therefore be defined as a torque capacity which will be limited by the torque capacity of the FVT.

If it is assumed that the torque capacity of the FVT at this point (mid range) equals prime mover torque, power recirculation at zero output speed will be:

$$PRo = \sqrt{\rho_F} \times Ro \times P_{Eng}$$

At the highest negative output speed from the device power recirculation could be even higher but the torque capacity is down to:

$$T_{out}\ (min) = \frac{T_{Eng}}{\sqrt[4]{\rho_F \times Ro}}$$

and

$$PR_{neg} = T_{out}\ (min) \times \sqrt{\rho_F} \times Ro$$

At high positive output speed the prime mover and the FVT torque capacities are additive and power from the direct engine input and from the IVT are shared. The torques here are therefore prime mover limited and of no interest to this assessment.

Set out below are examples (assuming that maximum torque capacity of the FVT at mid range equals prime mover torque capacity).

Prime mover torque = 1, Prime move power = 1

		At 0 Output Speed			At Negative output speed			
F	Ro	T_{out}	PRo	P_{out}	T_{out}(min)	PR_{neg}	P_{out}	
2	2	0.5(1)	1.41	0	.42	1.10	.4	
3	1	1	1.73	0	.76	1.32	.7	
4	0.666	1	1.33	0	1(1.06)	1.33	1	*
5	0.5	1	1.12	0	1(1.34)	1.12	1	*

Efficiencies are not taken into account in this arrangement.

* Lower torque and power than given by formulae due to torque limitations of prime mover and FVT to (1).

Referring now to Figure 2, an alternative embodiment is illustrated in which the same reference numerals have been used to refer to corresponding parts as were used in connection with the previously described embodiment but with the addition of 1000.

In this embodiment an engine 2011 drives a gear 2012 via a shaft 2013. The gear 2012 meshes with an idler gear 2018 which meshes with a gear 2019 provided on an input element 2020 of an FVT 2021 as described hereinbefore.

In this embodiment the output pulley 2023 of the FVT and its associated output element or shaft 2026 is connected directly to a sun gear 2101 of a three branch differential gear set (CD) 2500. The direct connection of the gear 2101 to the shaft 2026 affords a "direct drive connecting means between". That is to say unlike the previously described embodiment there is no intermediate differential gear train corresponding to the ICD 1017 of the previous embodiment. The shaft 2026 rotates at a speed which varies solely in dependence on the speed of gear 1029.

The shaft 2013 is directly connected to a planet carrier 2102 which is provided with the gear 2014 on its periphery. The planet carrier 2102 carries a set of planet gears 2103 which mesh with the sun gear 2101 and with an annulus 2104 which is connected via a clutch 2543 (corresponding to the fourth clutch 543 of the previously described embodiment and hence herein referred to as a fourth clutch) to a gear 2105 in mesh with a gear 2106 connected to the first drive member 2012 of the drive transmission.

The gear 2105 is also connected to the shaft 2026 by a clutch 2544, (corresponding to the fifth clutch 544 of the first embodiment and hence hereinafter referred to as the fifth clutch).

The planet carrier 2102, annulus 2104 and sun gear 2101 act respectively as first, second and third elements of the CD 2500.

Referring now to Figure 3, an alternative embodiment is illustrated which is similar to that of Figure 2 and in which the same reference numerals have been used to refer to corresponding parts as were used in the first embodiment but with the addition of 3000.

This embodiment differs from that of Figure 2 in that instead of a three branch differential gear set 2500 as in the embodiment of Figure 2, a four branch differential gear set is shown at 3500. In this embodiment the engine driven input shaft 3013 is connected to a planet carrier 3102 of the four branch differential gear set 3500.

The planet carrier 3102 carries a set of planet gears 3103 of stepped configuration having a first meshing part 3104 of greater diameter than a second meshing part 3105. the first meshing part 3104 engages a first sun gear 3106 which is carried by a shaft 3026 which constitutes an output element of a mechanical FVT 3021 which is the same as described in connection with the previous embodiments.

The smaller diameter meshing part 3105 of each planet gear 3103 meshes with an annulus 3107 and with a second sun gear 3108. The annulus 3107 is connected to a gear 3109 by a clutch 3543 (which corresponds to the fourth clutch 543 of the first described embodiment and hence is referred to herein as a fourth clutch), whilst the second sun gear 3108 is connected to the gear 3109 by a clutch 3544, which corresponds to the fifth clutch of the first described embodiment and hence is referred to herein as a fifth clutch.

The gear 3109 meshes with a gear 3110 fixed to a first drive member 3012 of the drive transmission.

A transmission embodying the invention and as described with reference to Figures 3 or 4 may be described mathematically by applying the following rules.

1

The FVT lower output speed shall be a prime mover r.p.m. which is also the synchronisation point in the centre of a duel range controllable differential.

2

ρ_F = Speed range of FVT

ρ out = Speed range of Oval Range CVT

3

ρ upper = Upper speed range of oval range CVT

4

ρ lower = Lower speed range of oval range CVT

5

$R0_1$ = Epicyclic ratio of lower range

6

$R0_2$ = Epicyclic ratio of upper range

7

Ro = Epicyclic ratio

8

P_{Eng} = Prime mover power

9

PR_{max} = Recirculating power

The embodiment with a three branch differential has very high recirculating power which must be accommodated by the FVT. If it is required to utilise full engine power down to the lower synchronisation point, i.e. the output torque = $R_o \times T_{Eng}$ the recirculating power is: If ρ_F = Ro

$PR_{max} = \rho_F \times P_{Eng}$

ρ dual range = ρ_F^2

For ρ_F = Ro + 1

ρ out = infinite

The example shown has a FVT with speed range of 3:1 or 4:1, Ro = 3 resulting in a dual range of 9:1 or infinite (0 output) if F > than 4, reversing of output is possible.

Mathematical analysis of the embodiment with the four branch differential is more complicated as the upper and lower ρ out become unequal. As this can be compensated for by also shifting the centre synchronisation points, i.e. having unequal upper and lower ρ_F's, the possible combinations are very great.

The most significant factor is that the recirculating powers through the FVT become very much lower and will generally be:

$$PR_{max} = \frac{\rho_F}{Ro_2} \times P_{Eng}$$

which would occur at the lower synchronisation point of the four branch control differential.

Zero output speeds will not be reached with this arrangement and a clutch start and reverse of a vehicle driven by this transmission is required.

Instead of the differential gear sets described hereinbefore in connection with the CD's of the first and third embodiments and the ICD of the first embodiment, alternative configurations of differential gear sets may be provided. Some alternatives are illustrated in Figures 10 to 14 hereof.

In these Figures, the alternative differential gear sets are illustrated in the environment of the CD 500 of the first embodiment so that the inputs on the first and third branches of the differential are shown from the gears 1015 and 1029. It will be appreciated that if desired any appropriate gear set or combination of gear sets illustrated in Figures 10 to 14 may be substituted for any of the differential gear sets described hereinbefore where appropriate and with appropriate modifications, as will be apparent to those of skill in the art.

Referring to Figure 10, the shaft 25 carries a sun gear 26 of a first stage summing "parallel axis epicyclic gear set" A. The sun gear 26 meshes with planet gears 28 carried by a planet carrier 29 and the planet gears 28 also mesh with an annulus 30. The annulus 30 acts as a first element, the planet carrier 29 acts as a second element and the sun gear acts as a third element of the summing transmission A.

The shaft 25 also carries a first bevel gear 31 of a second stage summing "cross axis (or bevel gear) epicyclic gear set" B. The gear 31 meshes with

planetary bevel gears 33 mounted on a planet carrier 34. The bevel gears 33 mesh with a second bevel gear 35 of the epicyclic bevel gear 32 which is connected to a drum 36.

The second bevel gear 35 acts as a first element of the "cross axis epicyclic gear set" 32 whilst the carrier 34 acts as a second element and the first bevel gear 31 as a third element thereof.

The planet carrier 34 is connected to a gear 27 which meshes with a gear 32 fixed to a shaft 37 which can be connected by a first clutch 38 to rotate with the input member 13.

The first and second stage summing gear sets A and B together provide a controllable four branch differential gear.

The shaft 25 may be connected by a second clutch 40 to a further bevel gear 41 of a reversing "cross axis epicyclic gear set" C. The bevel gear 41 meshes with planetary bevel gears carried by a planet gear carrier 44 which is anchored to a fixed part 45 of the transmission. The planetary bevel gears 43 mesh with a second further bevel gear 46 which is connected to the gear 27. The second further bevel gear 46 acts as a first element of the reversing gear set C whilst the bevel planet carrier 44 acts as a second element and the first further bevel gear 41 as a third element thereof.

The bevel gear 41 may be connected by a third clutch 47 to the shaft 16.

The planet carrier 29 of the summing gear set A is connectable by a fourth clutch 50, 50' to an output member 51 of the transmission which is connected by a gear 52 and a gear 53 to the driven shaft 12.

Alternatively, when the fourth clutch 50 (shown in the upper part of Figure 10) is disengaged the drum 36 may be connected by a fifth clutch 54 to the output member 51.

In a modification, shown in the bottom part of Figure 10, the fourth clutch 50' is provided between the annulus 30 of the summing gear set A and the planet carrier 34 of the epicyclic gear set B whilst the planet carrier 29 of the summing gear set A is connected directly to the output member 51.

In use, assuming that the vehicle is initially stationary so that the driven shaft 12 is stationary, the first and third clutches 38, 47 are disengaged whilst the second clutch 40 is engaged and the fourth clutch 50, 50' is engaged and the fifth clutch 54 disengaged.

The engine 1011 rotates the member 1029 as described hereinbefore. No drive is transmitted to the driven shaft 12.

As the gear 1029 starts to rotate the shaft 25 causes the gears 26 and 31 to rotate and, because the clutch 40 is engaged the bevel gear 41 on the reversing gear set C is also caused to rotate, all in the same direction.

Because of the effect of the bevel gears 43 of the reversing gear, the second bevel gear 46 thereof is caused to rotate in the reverse direction to the first bevel gear 41 and thus the gear 27 and the bevel gear carrier 34 of the epicyclic second stage summing cross-axis gear set B are caused to rotate in said reverse direction. Consequently the first element 30 of the summing gear set A is caused to rotate in the opposite direction to the direction of rotation of the third element 26 thereof.

Since the reversing gear set C is an epicyclic cross-axis bevel gear set having a gear ratio of unity the first element 30 and the third element 26 of the summing gear set A rotate at the same speed but in opposite directions. This causes the planet carrier 29 to rotate in the same direction as the first element 30 but at a slower speed dependent upon the relative numbers of teeth on the first and third elements. This forward rotation of the carrier or second element 29 is connected by the fourth clutch 50 to the output member 51 and hence via the gears 52 and 53 to the driven shaft 12. As the swash plate angle increases the speed of rotation increases with a corresponding decrease in torque. The transmission therefore provides a maximum torque when the vehicle is starting to move away from stationary.

When the gear 1029 is rotating at the same speed as the input element 18 and thus the first and second bevel gears 41, 46 of the reversing gear set C will be rotated at the same speed as the intermediate gear 15 and since the gears 14 and 32 are of the same diameter the gear 32 will be rotated by the gear 27 at the same speed as the input member 13. The first clutch 38 is then engaged. Since at this stage the speed of

rotation are synchronous the first and second clutches 38, 40 are simultaneously engaged so that drive is constantly transmitted.

Once the first clutch 38 has been engaged the gear 1029 is slowed and, shortly after, the second clutch 40 will automatically disengage. With further reduction in the speed of gear 1029 the sun gear 26 of the summing gear set A also slows whilst the first element 30 of the summing gear set A is rotated by the gear 35 via the planet carrier 34 of the epicyclic cross-axis transmission B either directly or in the modification shown in the bottom part of Figure 1 via the fourth clutch 50'. The slower rate of rotation of the sun gear 26 compared with the rate of rotation of the annulus or first element 30 causes faster rotation of the second element or carrier 29 and thus continued faster rotation of the output member 51.

When the gear 1029 is stationary the sun gear 26 is stationary whilst the annulus 30 continues to rotate at the same, in the present example, constant speed provided by the prime mover 11 and so the second element or carrier 29 continues to rotate faster.

As the gear 1029 is reversed the sun gear 26 rotates in the reverse direction at an increasing rate whilst the annulus 30 continues to rotate at a constant rate thus further increasing the rate of rotation of the carrier or second element 29 until the carrier 29 reaches the same speed of rotation as the annulus 30. At this stage the fourth clutch 50, 50' is disengaged and the fifth clutch 54 engaged. Again if desired, the fourth and fifth clutches may be simultaneously engaged for a period of time during changeover to avoid any interruption in drive transmission. This is possible because at this stage the drum 36 connected to the second bevel gear 35 of the epicyclic cross-axis gear set B is rotated by the first bevel gear 31 thereof at the same rate as the planet carrier 29 of the summing gear set A is rotated.

On changing the speed of gear 1029 towards zero the speed of the bevel gear 31 is decreased, whilst the carrier 34 of the epicyclic cross-axis gear set B is caused to rotate at the same speed by the gear 32 and thus the second bevel gear 35 is caused to rotate at a greater speed which is transmitted via the fifth clutch 54 to the output member 51.

As the speed of the gear 1029 is increased in the opposite direction the shaft 22 rotates in the opposite direction at an increasing speed, thus rotating the first bevel gear 35 at increasing speed in the opposite direction whilst the carrier 34 is rotated at the same speed thus causing still faster rotation of the second bevel gear 35 and hence of the output member 25.

When it is desired to drive the vehicle in reverse initially the FVT is adjusted, as explained hereinbefore, the opposite direction to that described hereinbefore for forward drive so that the output element 1029 is rotated in the reverse direction and hence drive again takes place similar to that described hereinbefore but in the reverse direction. When the swash plate angle has been increased so that the output element 22 is rotating at the same speed as the input element 18 but in the reverse direction the second clutch 40 is disengaged and the third clutch 47 engaged, the first clutch 38 remaining disengaged. Again the second and third clutches 40, 47 may be simultaneously engaged during changeover.

As the speed of gear 1029 is decreased towards zero the carrier 34 is driven in the reverse direction to that previously described by virtue of it being driven via bevel gear 41, planetary bevel gears 43 and second bevel gear 46 of the reversing gear set C, in the opposite direction to that in which it was driven by the gear 36. Otherwise the transmission operates in an exactly similar manner, but in the reverse direction, to that described hereinbefore for forward drive.

The summing gear sets A and B provide a controllable four element transmission in which first and third elements are provided by sun gears 26, 31 and gear 27 respectively and the second and fourth elements are provided by carrier 29 and drum 36 respectively.

The hereinbefore described transmission therefore provides forward or reverse drive up to the same maximum speed as well as providing a maximum torque at zero vehicle speed as the vehicle starts to move in either forward or reverse.

Referring now to Figure 11, a second alternative is described in which the same reference numerals have been used for corresponding parts but preceded by a 1.

This alternative differs from the previously described alternative by virtue of having an epicyclic parallel axis gear set 1B for the second stage summing set and an epicyclic parallel axis gear set 1C for the reversing gear set as well as having a range change set D. Again, the first and second stage gear sets 1A and 1B together provide a controllable four branch differential gear.

The reversing set 1C comprises a sun gear 141 which acts as a third element and an annulus 146 which acts as a first element and planetary gears 143 carried on a carrier 144 which acts as a second element and is anchored to a stationary part 161 of the transmission.

In other respects the reversing gear set 1C operates in the same manner as the reversing gear set 1C of the previously described embodiment.

The second stage summing set comprises a sun gear 131 which acts as a first element, epicyclic planet gears 133 carried by a carrier 134 which acts as a second element and the gears 133 are connected to gears 162 which mesh with an annulus 163 which acts as a third element and is connected to a drum 164.

The second stage summing set 1B operates in an analogous manner to the second stage summing train 1C of the previously described embodiment. The first and third elements of the four element differential gear are provided by sun gears 126, 131 and gear 127 respectively and the second and fourth elements are provided by carrier 129 and drum 164 respectively.

The range change set D comprises a sun gear 170 which acts as a third element of the range change epicyclic planetary train which meshes with planet gears 171 mounted on a carrier 172 which acts as a second element. The planet gears 171 mesh with an annulus 173 which acts as a first element and which can be connected by a clutch 174, hereinafter referred to as an eighth clutch, to a stationary part 175 of the transmission.

A sixth clutch 176 is provided to connect the planet carrier 129 of the summing gear set 1A to the sun gear 170 of the range change gear set D whilst a seventh clutch 177 is provided to connect the annulus 163 of the second stage summing set 1B to the carrier or second element 172 of the range change set D.

In use, when the vehicle is stationary and it is desired to drive the vehicle in a forward direction the second clutch 140 is engaged, as is the fourth clutch 150 and the drive is transmitted by the annulus 134 and sun gear 126 rotating at the same speeds in opposite directions as described hereinbefore, thus causing the carrier 129 to rotate and its drive to be transmitted by the fourth clutch 150 to the output member 151.

As in the previously described embodiment, when the gear 1029 reaches its maximum speed so that the motor 121 is rotated at the same speed as the pump 119 the first clutch 138 can be engaged and the second clutch 140 then disengages so that the gear 127 is rotated via the gear 132 by the engine 111.

Operation of the first stage set 1A is as previously described except that instead of the fourth clutch 150 being engaged the sixth clutch 176 is engaged so that the sun gear 170 of the range change set D is driven and, in addition, the eighth clutch 174 is engaged so that the planet carrier 172 is driven to rotate the output shaft 151.

When the speed of gear 1029 has been reduced to zero and reversed and increased to its maximum the sixth clutch 176 is disengaged and the seventh clutch 177 engaged so that the rotation of the annulus 163 of the second range set 1B' is transmitted to the sun gear 170 of the range change set D whilst the eighth clutch 174 thereof remains engaged so that drive is transmitted by the carrier 170 to the output shaft 151.

When the speed of gear 1029 has again been moved through zero and to the maximum in the opposite direction the seventh and eighth clutches 177 and 174 are released and the fourth clutch 150 engaged so that the rotation of the carrier 129 of the summing transmission 127 is connected directly to the output shaft 151.

When the speed of gear 1029 has been moved through zero to the maximum in said opposite direction the fourth clutch 150 is disengaged and the fifth clutch 154 engaged so that the annulus 163 of the second range set 1B' is connected to the carrier 172 of the range change set but because the eighth clutch 174 is disengaged

the carrier 123 simply rotates at the same speed as the annulus 163 to drive the output shaft 151.

Operation in the reverse direction is exactly analogous except that, as in the first embodiment, except that during hydro-mechanical drive the first clutch 138 is disengaged and the third clutch 147 engaged.

Referring now to Figure 12 there is illustrated a third alternative in which the same reference numerals have been used for the corresponding parts as were used in connection with the first alternative but preceded by a 2.

The embodiment shown in Figure 12 is similar to that of Figure 10 except that the reversing gear set 2C and the second stage summing gear set 2B each comprise a "sun gear compound parallel axis epicyclic gear set". Again, the first and second stage gear sets 2A and 2B together provide a controllable four branch differential gear.

The reversing gear set 2C comprises an annulus 259, which acts as a first element, and which is maintained stationary and a carrier 261, which acts as a second element, and which carries pairs of intermeshing planet gears 243<u>a</u>, 243<u>b</u>. One planet gear 243<u>a</u> of each pair of planet gears is in mesh with the annulus 259 whilst the other planet gear 243<u>b</u> of each pair of planet gears is in mesh with a sun gear 241, which acts as a third element, and which is connectable by a first clutch 240 to the shaft 225.

The "sun wheel compound parallel axis gear set" of the second stage summing gear set 2B similarly comprises an annulus 260, which acts as a <u>second</u> element, and which is connected to rotate with the carrier 261 of the reversing gear set 2C and is connectable by a fourth clutch 250 to the annulus 236 of the summing gear set 2A. The second stage summing gear set 2B also comprises a planet carrier 262, which acts as a <u>first</u> element, and which carries pairs of intermeshed planet gears 233<u>a</u>, 233<u>b</u>. One gear 233<u>a</u> of each pair of planet gears is in mesh with the annulus 260 whilst the other gear 233<u>b</u> of each pair of planet gears is in mesh with a sun gear 231, which acts as a third element. The carrier 262 is connectable by the fifth clutch 254 to the carrier 229 of the summing gear set 2A.

It is to be noted that with the "sun wheel compound parallel axis epicyclic gear set" type of reversing gear the role of the annulus 259 and the carrier 261 are reversed compared with their roles in the other embodiments described herein and as a result a 1:1 reverse is provided so that the sun gear 241 and the carrier 261 rotate at the same speed but in opposite directions.

In use, when it is desired to drive in a forward direction starting from an at rest condition, the second clutch 240 is engaged and the fourth clutch 250 is engaged, whilst the first and third clutches 238 and 247 are disengaged.

Drive is therefore transmitted in an exactly analogous manner to that described with reference to Figure 8, i.e. by virtue of the sun wheel or third element 226 of the summing gear set 2A being driven by the shaft 225 at the same speed but in the opposite direction to the annulus 230 which is driven via fourth clutch 150 and annulus 260 of the second range gear set 2B which is driven from the carrier 261 of the reversing gear set 2C.

As in the first alternative when the speed of gear 1029 is increased to maximum the first clutch 238 is engaged and then the second clutch 240 disengages.

Thereafter, the annulus 260 is driven by the gear 227 via the gear 232 and first clutch 238 from the input member 213 at a constant speed whilst the speed of the sun wheel 226 of the summing gear set 2A is first decreased to zero and then increased in the reverse direction thereby driving the carrier 229 of the summing gear set 2A at an increasing speed as described in connection with the first embodiment.

After the speed of gear 1029 has increased to maximum in the reverse direction the fifth clutch 254 is engaged and the fourth clutch 250 disengages. In this condition the drive is transmitted to the output 251 by a fifth clutch 254 from the carrier 262 of the second stage summing set 2B which is rotated as a result of the annulus 260 continuing to be rotated at the same speed by the gear 227 from the input 213 whilst the sun wheel 231 is first decreased in speed and then increased in speed in the opposite direction as the swash plate angle is progressively reversed.

When it is desired to drive the vehicle in a reverse direction then initially drive is as a result of rotating the gear 1029 in the reverse direction to that required for forward drive.

When the speed of gear 1029 is increased to maximum the third clutch 247 is engaged and the second clutch 240 disengages, whilst the fourth clutch 250 remains engaged.

When the clutch 247 is engaged the inner member 241 of the reversing gear set 2C is rotated in the reverse direction and since the annulus 259 is fixed the carrier 261 is rotated in the reverse direction to that achieved in forward drive. Otherwise the drive path is as described at this stage in connection with the first embodiment.

The other stages are as described for the forward direction except that the annulus 260 is driven in the reverse direction via the reversing gear set 2C as described hereinbefore.

The first and third elements of the four element differential gear are provided by sun gears 226, 231 and gear 227 respectively and the second and fourth elements by annulus 260 and carrier 262 respectively.

Referring now to Figure 13 there is illustrated a fourth alternative in which the same reference numerals have been used for the corresponding parts as were used in connection with the first alternative but preceded by a 3.

The alternative shown in Figure 13 is similar to that of Figure 10 except that the reversing gear set 3C and the second stage summing gear set 3B each comprise a "twin annulus compound parallel axis epicyclic gear set". Again, the first and second stage gear sets 3A and 3B together provide a controllable four branch differential gear.

The reversing gear set 3C comprises a first annulus 346, which acts as a first element, and a planet carrier 344, which acts as a second element, and which is maintained stationary. The carrier 344 carries pairs of intermeshed planetary gears 343a, 343b. One gear 343a of each pair of planetary gears meshes with the annulus 346 whilst

the other gear 343b of each pair of planetary gears meshes with a second annulus 341, which acts as a third element.

The planetary gears 343a and 343b are axially offset to enable such mutual intermeshing and engagement with the annuli 346 and 341.

The second stage summing gear set 3B is of similar construction comprising a first annulus 335, which acts as a first element, and a planet carrier 334, which acts as a second element, and which carries pairs of intermeshed planetary gears 333a, 333b. One gear 333a of each pair of planetary gears meshes with the first annulus 335 whilst the other gear 333b of each pair of planetary gears meshes with a second annulus 331, which acts as a third element.

The second annulus 341 of the reversing gear set 3C is connectable to the shaft 325 by the clutch 340 or to the gear 315 by the clutch 347 analogous to the first embodiment, whilst the second annulus 346 of the reversing gear set is connected to gear 327 and carrier 334 of the second stage summing gear set 3B and the second annulus 331 of the gear set 3B is connected to the shaft 325.

In use, when it is desired to drive in a forward direction starting from an at rest condition, the second clutch 340 is engaged and the fourth clutch 350 is engaged, whilst the first and third clutches 338 and 347 are disengaged.

Drive is therefore transmitted in an exactly analogous manner to that described with reference to Figure 8, i.e. by virtue of the sun wheel or third element 326 of the summing gear set 3A being driven by the shaft 325 at the same speed but in the opposite direction to the annulus 330 which is driven via the carrier 334 of the second stage summing gear set 3B which is driven from the first annulus 346 of the reversing gear set 3C which is caused to rotate at the same speed but in the opposite direction to the second annulus or third element 341 of the gear set 3C by virtue of the intermeshing planetary gears 343a, 343b and the fixed carrier 344 thereof.

As in the first alternative, when the speed of gear 1029 is increased to maximum the first clutch 338 is engaged and then the second clutch 340 disengages.

Thereafter, the carrier 334 is driven by the gear 327 via the gear 332 and the first clutch 338 from the input member 313 at a constant speed, whilst the speed

of the sun wheel 326 of the summing gear set 3A is first decreased to zero and then increased in the reverse direction, thereby driving the carrier 329 of the summing gear set 3A at an increasing speed, as described in connection with Figure 8.

After the speed of gear 1029 has increased to maximum in the reverse direction, the fifth clutch 354 is engaged and the fourth clutch 350 disengages. In this condition the drive is transmitted to the output 351 by a fifth clutch 354 from the first annulus 325 of the second stage summing gear set 3B which is rotated as a result of the carrier 334 continuing to be rotated at the same speed by the gear 327 from the input 313, whilst the second annulus or third element 331 is first decreased in speed and then increased in speed in the opposite direction so that the swash plate angle is progressively reversed.

When it is desired to drive the vehicle in a reverse direction the initial drive is as a result of rotating the output element 322 of the hydrostatic transmission 320 in the reverse direction to that of the forward drive.

When the speed of gear 1029 is increased to maximum, the third clutch 347 is engaged and the second clutch 340 disengages, whilst the fourth clutch 350 remains engaged.

When the clutch 347 is engaged, the second annulus or third element 341 of the reversing gear set 3C is rotated in the reverse direction and since the planet carrier 344 is fixed, the first annulus or first element 346 is rotated in the reverse direction to that achieved in forward drive. Otherwise the drive path is as described at this stage in connection with the first alternative.

The other stages are as described for the forward direction except that the planet carrier 334 is driven in the reverse direction by the reversing gear set 3C as described hereinbefore.

The first and third elements of the controllable four element differential gear set are provided by sun gear 326, annulus 331, and carrier 334 respectively, and the second and fourth elements by the carrier 329 and drum 336.

Referring now to Figure 14, there is illustrated a fifth alternative in which the same reference numerals have been used for the corresponding parts as were used in connection with the first embodiment but preceded by a 4.

The alternative shown in Figure 14 differs from that of the preceding embodiments in that it utilises solely spur gears and thus is economical to manufacture.

The transmission 410 has an input member 413 adapted to be driven by a prime mover 411. The input member 413 carries a gear 414 which meshes with an intermediate gear 415 carried on an intermediate shaft 416 and meshed with an idler gear 415a which may provide an implement and pump drive which meshes the gear 1015.

The gear 1029 meshes with an idler gear 423a and with a gear 424 carried on a shaft 425.

The shaft 425 carries a sun gear 426 of a summing "spur gear epicyclic gear set" 4A. This gear set has pairs of intermeshed planet gears 428a, 428b carried by a planet carrier 429. One planet gear 428a of each pair meshes with a first spur gear 460 mounted for rotation about the axis Y-Y. The first spur gear 460 acts as a first element, planet carrier 429 acts as a second element and sun gear 426 which meshes with the other planet gear 428b of each pair of planet gears comprises a second spur gear and acts as a third element of the summing transmission 4A. A third spur gear 461, also mounted for rotation about the axis Y-Y, meshes with the one planet gear 428a of each pair of planet gears and acts as a fourth element of the summing transmission 4A.

The shaft 425 also carries a sun gear 431 of a second stage summing "spur gear epicyclic gear set" 4B. This second stage summing gear set comprises pairs of intermeshed planet gears 433a, 433b carried by a planet carrier 434 which is connected to rotate with the fourth element 461 of the summing gear set 4A. A spur gear 462, mounted to rotate about the axis Y-Y meshes with the one planet gear 433a of each pair of planet gears and provides a first spur gear of the second stage summing gear set 4B and acts as a first element thereof. The carrier 434 acts as a second element whilst the sun gear 431 provides a second spur gear of the gear set 4B and acts as a third element of the set 4B. Again, the first and second stage summing gear sets 4B, together provide a controllable four branch differential gear.

In this alternative a reversing gear set 4C is provided which comprises a "spur gear lay shaft reversing gear set". The first spur gear 460 of the summing gear set 4A meshes with a gear 432 fixed to a shaft 437 which can be connected by a first clutch 438 to rotate with the input member 413.

The shaft 425 may be connected by a second clutch 440 to a spur gear 441 of the "spur gear lay shaft reversing gear set 4C". The spur gear 441 meshes with an idler gear 441a rotatable about an axis parallel to the axis Y-Y and which meshes with a further spur gear 441b fixed to rotate with the shaft 437. The gear 441 may be connected by a third clutch 447 to the shaft 416.

The planet carrier 429 of the summing gear set 4A is connectable by a fourth clutch 450 to a gear 465 which meshes with a gear 464 fixed to an output member 451 of the transmission, which itself provides a rear driven shaft 412, and is connected via a gear 463 to a front driven shaft 412a.

Alternatively, the planet carrier 429 of the summing gear set 4A may be connected by a fifth clutch 454 to a gear 466 which meshes with a further gear 467 fixed to the member 451.

Further alternatively, the first element 462 of the second stage summing gear set 4B may be connected by a sixth clutch 468 to the gear 461.

In use, when the vehicle is stationary and it is desired to drive the vehicle in a forward direction the second clutch 440 is engaged, as is the fifth clutch 454 and the drive is transmitted by the first element 460 and the third element 426 rotating at the same speeds in opposite directions thus causing the carrier 429 to rotate and its drive to be transmitted by the fifth clutch 454 to the output member 451 via gears 466, 467.

As in the previously described alternatives, when the speed of gear 1029 reaches its maximum, the first clutch 438 can be engaged and the second clutch 440 then disengages so that the gear 460 is rotated via the gear 432 by the engine 411.

Once the first clutch 38 has been engaged and the second clutch disengaged further reduction in swash plate angle causes the speed of the output element 422 of the hydrostatic pump 421 to slow and hence the sun gear 426 of the summing gear

set 4A also slows, whilst the first element 460 of the summing gear set 4A is rotated by the gear 432 at the same speed by the engine 411. The slower rate of rotation of the sun gear 426 compared with the rate of rotation of the first element 460 causes faster rotation of the second element or carrier 429 and thus continued faster rotation of the output member 451.

As the gear 1029 is reversed the sun gear 426 rotates in the reverse direction at an increasing rate whilst the first element 460 continues to rotate at a constant rate, thus further increasing the rate of rotation of the second element 429 and hence of the output shaft 451 until the carrier 429 attains the same speed of rotation as the first element 460. At this stage the sixth clutch 468 is engaged and the fifth clutch 454 automatically disengages whilst the drive is taken up by the sixth clutch 468. On changing the speed of gear 1029 towards zero thus decreasing the speed of the sun gear 431 whilst the carrier 434 of the second stage gear set 4B continues to rotate at the same speed as the motor 411 by virtue of its connection to the fourth element 461 and its connection through the planetary gear 428a with the gear 460 which is in mesh with the gear 432. Thus the first element 462 is caused to rotate at a greater speed which is transmitted via the sixth clutch 468 to the output member 451 via the gears 466, 467.

As the speed of gear 1029 is increased in the opposite direction the sun gear 431 of the second stage transmission 4B is rotated at an increasing speed in the opposite direction, whilst the carrier 34 is continued to be rotated at the same speed by the engine 411, thus causing still faster rotation of the first element 462 and hence of the output member 451.

When the gear 1029 is at maximum speed the fourth clutch 450 is engaged and the sixth clutch 468 automatically disengages so that drive is again transmitted from the carrier 429 of the first stage gear set 4A but in this case is transmitted to the output member 451 via gear 465 and gear 464.

Reverse operation is analogous to that described in connection with the previous embodiment.

The first and third elements of the four element differential gear set are provided by sun gears 426, 431 and sun gear 460 respectively and the second and fourth elements are provided by carrier 429 and sun gear 462 respectively.

Referring to Figure 15, a two-range drive transmission 4010 is provided to connect a prime mover 4011 of a vehicle to the driving wheels thereof by a drive shaft 4012, which comprises a first drive member of the drive transmission. The prime mover may be a diesel engine and the vehicle may be a construction vehicle such as a front end loader.

The transmission 4010 has an input member 4013 comprising a second drive member of the drive transmission and which is driven by the prime mover 4011. The transmission 4010 is a power-splitting transmission which has a four branch controllable differential (CD) 4500 and a finite continuously variable transmission (FVT) 4021.

The input member 4013 carries a gear 4014 which meshes with an idler gear 4018 which meshes with a gear 4019 provided on an input element 4020 of the FVT 4021.

The FVT 4021 is of conventional type comprising a pair of split pulleys 4022, 4023 having variably separable cheeks 4024 which together define a frusto conical recess of variable width in which a continuous loop member 4025 is drivingly received. By varying the spacing between the cheeks 4024 the radius at which the belt 4025 engages the pulleys 4022, 4023 can be varied thereby varying the ratio of the speed of rotation of the output pulley 4022 on the input pulley 4022. It is preferred that the loop 4025 is a metal, such as steel, pusher belt.

The mechanical continuously variable transmission 4021 may be of other kind such as a toroidal disc type drive comprising two discs each with a toroidal working surface engaged by a roller, the axis of rotation of the roller being adjustable to vary the radial positions at which the roller engages the toroidal surfaces thereby to adjust the relative rates of rotation of the two discs.

All such mechanical continuous variable transmissions have a finite ratio of input speed to output speed since the output speed can never reach zero.

The input member 4013 is also connected to a first element of the CD 4500, a second element of the CD is connectable via a clutch 4543 and gears 4109, 4110 to the first drive member 4012 of the transmission. A third element of the CD is connected to the output element 4026 of the FVT 4021 and a fourth element of the CD is connectable by clutch 4544 and gears 4109, 4110 to the first drive member 4012.

According to the first more specific aspect of the present invention the CD 4500 is as now to be described with reference to Figures 16 and 17.

The member 4013 is directly connected to a planet carrier 4102. The direct connection of the member 4013 to the planet carrier 4102 affords a "direct drive connecting means". That is to say there is no intermediate differential gear train. The carrier 4102 rotates at a speed which varies solely in dependence of the speed of the member 4013.

The planet carrier 4102 is provided with the gear 4014 on its periphery. The planet carrier 4102 carries a set of planet gears 4103 of stepped configuration having a first meshing part 4104a disposed between a second, larger diameter meshing part 4104b and a third, smaller diameter, meshing part 4104c.

The output pulley 4023 of the FVT 4021 is connected by its associated output element or shaft 4026 to a first sun gear 4101 of the CD 4500. The direct connection of the gear 4101 to the shaft 4026 affords a "direct drive connecting means" therebetween. That is to say there is no intermediate differential gear train. The shaft 4026 rotates at a speed which varies solely in accordance with the speed of the output pulley 4023.

The first sun gear 4101 meshes with the second meshing part 4104b of the planet gears 4103 and acts as a third element of the CD 4500.

The first meshing parts of 4104 of the planet gears 4103 mesh with an annulus 4107 which acts as a second element of the CD and which is connected by a tubular member 4107a to the clutch 4543 so as to be connectable to the gear 4109.

The third meshing parts 4104c mesh with a second sun gear 4108 which acts as fourth element of the CD and which is connected by a tubular member 4108a to the clutch 4544 so as to be connectable to the gear 4109. As can be clearly seen from

Figure 2 the fourth element is disposed between the third and second elements and all three of these elements are coaxial and extend from one side of the CD. The first element is also coaxial with the other elements but extends from the opposite side of the CD.

By providing three meshing portions on the planet gears the ratio of the output of the second sun gear to the annulus can be altered which enables the two output ratios to be equalised.

The output ratio is

$$\rho = 1 + \frac{\rho_F}{R_{02}} \quad \text{and } R_{01} = R_{02} + \rho_F$$

In the example illustrated in Figures 2 and 3 $\rho_F = 2$

$R_{01} = 8 \quad R_{02} = 6$

Upper and lower ρ out $= 1 + \dfrac{\rho_F}{R_{02}} = 1.33$

therefore the power recirculation is 33%.

Referring now to Figures 18 and 19 there is shown an alternative form of CD 4500 according to the second more specific aspect of the invention.

In this case the same reference numerals are used as were used in connection with Figures 16 and 17, but with an initial figure 5.

The shaft 5013 driven by the prime mover 4011 is again directly connected to a planet carrier 5102 provided with the gear 5014. The planet carrier 5012 acts as a first element of the transmission. The output shaft 5026 of the FVT 4021 is again directly connected to a first sun gear 5101 and acts as a third element of the transmission. The planet carrier 5102 carries, in the present example, three first planet gears 5103 and three second planet gears 5104. These gears are mounted, in conventional manner, on the carrier 5102.

The first gears 5103 have a first meshing part 5105<u>a</u> of larger diameter than a second meshing part 5105<u>b</u>. The first meshing parts 5105<u>a</u> mesh with the first sun gear 5101. The second meshing parts 5105<u>b</u> mesh with a respective one of the second planets 5104. The second planets 5104 also mesh with a second sun gear 5106 which acts

as a second element of the transmission and is connected by a tubular member 5106a to the clutch 4543 mentioned herebefore. The second meshing parts 5105b mesh with a third sun gear 5107 which acts as a fourth element of the differential and which is connected by a tubular member 5107a to the clutch 4544.

As can be clearly seen from Figure 18 the fourth element is disposed between the third and second elements and all three of these elements are coaxial and extend from one side of the CD. The first element is also coaxial with the other shafts but extends from the opposite side of the CD.

By providing second or idler planets 5104 mounted on the carrier 5102 in engagement with the second sun gear, the ratio of the outputs of the two sun gears providing the second and fourth elements, can be altered.

The output ratio is

$$\rho = 1 + \frac{\rho_F}{R_{02}} \quad \text{and } R_{01} = R_{02} + \rho_F$$

In the example illustrated in Figures 4 and 5 $\rho_F = 3.6$

$R_{01} = 12.2 \quad R_{02} = 8.6$

Upper and lower ρ out $= 1.42$

therefore power recirculation is 42%.

The mode of operation of the drive transmission described hereinbefore is similar to the mode of operation of the drive transmissions described with reference to Figure 2 or Figure 3 hereof.

Initially the engine will be running at a desired speed and the output element 4023 of the FVT will be providing a maximum output speed and the clutch 4543 will be engaged. Thus the third element of the transmission is rotated in the same direction as, and at a faster speed than, the first element by a factor of ρ_F. The resultant of the inputs causes the second element to rotate at a relatively slow speed and the fourth element to rotate at a relatively high speed. Since the clutch 4543 is engaged the relatively slow speed of rotation of the second element in the same opposite direction

as the first and third elements is transmitted by the gears 4109, 4110 to the output drive member 4012.

To increase the speed of the vehicle the FVT is adjusted to decrease the speed of the output element 4023 which causes progressively faster rotation of the second element and progressively slower rotation of the fourth element.

A situation is reached where the speeds of rotation of the first, second, third and fourth elements become synchronous, i.e. at engine speed, and at that stage the clutch 4544 is engaged and the clutch 4543 disengaged. This synchronous condition is arranged to be at the minimum output speed of the output member 4023 of the FVT, i.e. engine speed.

To further increase the speed of the vehicle the output element 4023 of the FVT is caused to rotate progressively faster which causes a progressive increase in speed of the fourth element of the transmission and a decrease in speed of the second element.

For example, when the upper and lower ρ out is 1.33, and the engine speed is 2000 rpm, the slowest speed of the second element is $2000 \div 1.33 = 1500$ rpm whilst its faster speed of the fourth element is $2000 \div 1.33 = 2660$ rpm.

Referring now to Figure 20, there is shown a diagrammatic illustration of a four-range drive transmission similar to that shown in Figure 15. In Figure 20 the same reference numerals are used as were used in Figure 1 to refer to corresponding parts.

The four-branch differential 4500 of Figure 20 may comprise a four-branch differential as described hereinbefore with reference to Figures 16 and 17 or Figures 18 and 19.

The transmission of Figure 20 differs from that of Figure 15 by virtue of providing four output speed ranges in contrast to the two output speed capability of the transmission shown in Figure 15.

Referring now to Figure 20, the second element of the four-branch differential 4500 is provided with a gear 4600 which meshes with a gear 4601 which can be connected by a clutch 4602 to an intermediate shaft 4603 which is fixed to a gear 4604

which meshes with a gear 4605 fixed to a hollow shaft 4606 which is provided with a further gear 4607 which meshes with a gear 4110 on the first drive member or output member 4012.

Power transmission along the path just described provides a first, low speed range.

The fourth element of the four-branch differential 4500 is provided with a gear 4608 which meshes with a gear 4609 connectable by a clutch 4610 to the intermediate shaft 4603. Drive transmitted from the fourth element through the gears 4608, 4609 and clutch 4610 is then transmitted via gear 4604, 4605 and 4607, 4110 to the first drive member 4012 and provides a second speed range.

The gear 4600 on the second element of the differential is connectable by a clutch 4611 directly to the hollow shaft 4606 and then drive is transmitted via gears 4607 and 4110 to the first drive member 4012. Drive along the last described path provides a third speed range.

The fourth element of the four-branch differential 4500 is connectable by a further clutch 4612 to the hollow shaft 4606 and then drive is transmitted via gears 4607 and 4110 to the first drive member 4012, thus providing a fourth, highest range.

Of course, only one of the above described clutches 4602, 4610, 4611 and 4612 are engaged at any one time, the other three clutches being disengaged. As in the embodiment of Figure 15, as a clutch is disengaged, then the next clutch is engaged at a range change point, the speeds of rotation of the elements to be connected by the respective two clutches are rotating at the same speed as a result of appropriate adjustment of the FVT in a manner analogous to that described in connection with the Figure 15 embodiment. Thus, initially, the engine will be running at a desired speed and the output member 4023 of the FVT will rotate at a maximum speed so that the second element of the four-branch differential will be rotating at its slowest speed and the fourth element at its fastest speed, as described hereinbefore, and the clutch 4602 will be engaged.

The FVT will then be adjusted to decrease the speed of the output member 4023, decreasing the speed of the fourth element and increasing the speed of

the second element and so increase the speed of the vehicle. This continues until the speeds of rotation of the first, second, third and fourth elements of the four-branch differential become synchronous, at engine speed. At that stage the clutch 4610 is engaged and the clutch 4602 disengaged. The synchronised condition is at the minimum output speed of the output member 4023 of the FVT, i.e. engine speed.

To further increase the speed of the vehicle the output member 4023 of the FVT is caused to rotate progressively faster, which causes a progressive increase in the speed of the fourth element of the transmission and a decrease in the speed of the second element until they are rotating at their respective fastest and slowest speeds, which corresponds to their initial condition as described above.

When the FVT output member 4023 is rotating at its maximum speed the hollow shaft 4606 is rotated by the fourth element via the gears 4605/4604 and the gears 4608/4609 at the same speed as the gear 4600 is rotated by the second element of the transmission, because the two pairs of gears 4605/4604 and 4608/4609 are arranged to give a speed ratio of ρ out^2.

Thus, the two sides of the clutch 4611 are in synchronism and therefore the clutch 4611 can be engaged and the clutch 4610 disengaged.

To further increase the speed of the vehicle the output member 4023 of the FVT is caused to decrease in speed towards engine speed, thus causing the second element to increase its speed whilst the speed of the fourth element is decreased until the second and fourth elements again rotate at the same speed as each other and at the same speed as the output member 4023 so that all elements of the four-branch differential 4500 again rotate at the same, engine, speed as described at the changeover point from first range to second range. At this stage both sides of the clutch 4612 are rotating at the same speed and hence the clutch 4612 can be engaged and the clutch 4611 disengaged. To further increase the speed of the vehicle the output member 4023 is caused to increase in speed causing increase in the speed of the fourth element and decrease in the speed of the second element.

If desired, the transmission may be provided with further ranges in an analogous manner to those described hereinbefore by providing appropriate clutches and

gears of appropriate ratio to accommodate the difference in speeds where the changeover occurs when the second and fourth elements are not rotating at the same speed.

Furthermore, if desired, a three-range transmission may be provided. Such a three-range transmission is of a similar configuration to that shown in Figure 20 except that the clutch 4602 and the gears 4600, 4601 are omitted. In this case the lowest range corresponds to the second range described hereinbefore and the output is taken from the fourth element of the four-branch differential via the clutch 4610 and the sequence of operations is as described hereinbefore for operation of the second to fourth ranges which, in this modification, provides first to third ranges.

Although the four branch controllable differential gears described herebefore with reference to Figures 16 to 20 have been described as being used in a drive transmission having an FVT to provide an input to their respective third elements as illustrated in Figure 15, the differential gears per se may be used in any other desired application.

Referring now to Figure 21, there is shown an alternative form of FVT which may be used in place of the split pulley type illustrated in the previous Figures.

In Figure 21 there is shown an FVT 8000 of a toroidal disc drive type comprising a pair of relatively rotatable members 8001, 8002 which are generally disc shaped and are provided with a pair of part-toroidal working surfaces 8003. A rotatable element 8004, generally referred to as a roller is disposed between and in rolling and driving engagement with the surfaces 8003 to transmit drive between the members. The axis of rotation 8005 of the roller 8004 is adjustable to vary the radial positions at which the roller 8004 engages the part-toroidal surfaces 8003 and hence permit continuous variation of the ratio between the members.

If desired, more than two members having associated working surfaces engaged with a roller may be provided and each pair of working surfaces may have more than one roller engaged therewith.

One member 8001 of the FVT is connected to an input shaft such as the shaft 1020 of Figure 1 and the or each other member 8002 is with a gear 8006 which

meshes with a gear 8007 which is fixed to rotate with a shaft such as the shaft 1026 of Figure 1.

In other respects the structural features of the transmission are as described in connection with Figure 1 and analogous with the other embodiments described hereinbefore.

Transmissions as described hereinbefore may be of any desired application but is particularly intended for use in a construction vehicle of the kind having a moving implement. One such vehicle is illustrated in Figures 22 and 23 where a vehicle 9001 is provided with a front end loader 9002 and a back hoe excavator 9003, both of conventional kind. The front end loader 9002 comprises a bucket 9003 pivotally mounted on a pair of spaced parallel lift arms 9004 which are pivotally mounted on the vehicle for raising and lowering movement by hydraulic rams 9005. In addition, the arms are provided with a pair of crowd rams 9006 for causing crowd movement of the bucket 9003 about its pivotal connection to the arms 9004 via a crowd linkage 9007.

The back hoe excavator 9003 comprises a bucket 9008 pivotally connected to a dipper arm 9009 and movable for crowd movement relative thereto by a crowd ram 9010 and crowd linkage 9011. The dipper arm 9009 is pivotally mounted at the upper end of a boom 9012 under the control of a dipper arm ram 9013, the boom itself being movable up and down by a raising and lowering ram 9014. The boom 9012 is also pivotal about a vertical axis and can also be slid transversely of the rear of the tractor.

The vehicle 9001 has an engine 9014 which provides motive power for the vehicle and also pressurises hydraulic fluid for operation of the front end loader and back hoe excavator. In addition the vehicle has four ground engageable wheels 9015.

The wheels 9015 are driven from the engine 9014 by a transmission T which is as described in any of the previous embodiments, the input member of the transmission T being driven from the engine 9014 via a shaft 9016 and a rear output member of the transmission being connected to a rear drive shaft 9017 which is connected via a differential 9018 and drive shafts 9019 to the rear wheels of the vehicle.

A forward output member is connected via a shaft 1020 to drive the front wheels via a differential 9021 and drive shafts 9022.

If desired, only the rear wheels of the vehicle may be driven, in which case the forward drive member and associated shaft 9020, differential 9021 and drive shafts 9022 may be omitted.

The features disclosed in the foregoing description, or the accompanying drawings, expressed in their specific forms or in terms of a means for performing the disclosed function, or a method or process for attaining the disclosed result, or a class or group of substances or compositions, as appropriate, may, separately or in any combination of such features, be utilised for realising the invention in diverse forms thereof.

CLAIMS:

1. A drive transmission comprising a finite continuously variable transmission (FVT) having a first element and a second element and in which the ratio of the rotational speed of the first element to that of the second element is continuously variable over a finite range and a controllable differential (CD) having first, second and third elements and wherein the second element of the CD is connectable to a first drive member of the drive transmission, the first element of the FVT and the first element of the CD are connected to a second drive member of the drive transmission and the second element of the FVT is connected to the third element of the CD.

2. A transmission according to claim 1 wherein the first and second elements of the FVT comprise input and output members respectively, the first and third elements of the CD comprise first and second input members whilst the second element comprises an output member, and the first drive member of the drive transmission comprises an output member and the second drive member of the drive transmission comprises an input member.

3. A transmission according to claim 1 or claim 2 wherein the transmission includes an intermediate controllable differential (ICD) having first, second and third elements and wherein the first element of the ICD is connected to said second drive member, the third element of the ICD is connected to the second element of the FVT and the second element of the ICD is connected to the third element of the CD.

4. A transmission according to claim 3 wherein the first and third elements of the ICD comprise first and second input elements thereof whilst the second element of the ICD comprises an output element.

5. A transmission according to claim 3 or claim 4 wherein the CD comprises a "parallel axis epicyclic gear set", or a "cross axis epicyclic gear set", or a "sun wheel compound parallel axis epicyclic gear set", or a "twin annulus compound parallel axis epicyclic gear set", or a "spur gear epicyclic gear set", or an "annulus and twin sun gear epicyclic gear set".

6. A transmission according to claim 3 or claim 4 wherein the CD comprises a four-branch CD having a fourth element in addition to said first, second and third elements and said third and fourth elements being alternately connectable to the first drive member of the drive transmission.

7. A transmission according to claim 6 wherein the fourth element of the CD comprises an output member.

8. A transmission according to claim 6 or claim 7 wherein the CD is a controllable four branch differential gear and comprises a first stage summing gear set and a second stage summing gear set.

9. A transmission according to claim 8 wherein the first stage summing gear set comprises a "parallel axis epicyclic gear set" or a "spur gear epicyclic gear set" and the second stage summing gear set comprises a "parallel axis epicyclic gear set" or a "cross axis epicyclic gear set" or a "sun wheel compound epicyclic gear set" or a "twin annulus compound axis epicyclic gear set", or a "spur gear epicyclic gear set".

10. A transmission according to any one of claims 3 to 9 wherein the ICD comprises a "parallel axis epicyclic gear set", a "cross-axis epicyclic gear set", a "sun wheel compound parallel axis epicyclic gear set", a "twin annulus compound parallel axis epicyclic gear set", or a "spur gear epicyclic gear set".

11. A transmission according to any one of claims 3 to 10 wherein a reversing gear is connectable between the output element of the ICD and said first element of the CD.

12. A transmission according to claim 1 or claim 2 wherein the second element of the FVT is connected to the third element of the CD by a direct drive connecting means and the second element of the CD and the second element of the FVT are alternately connectable to said first drive member of the drive transmission.

13. A transmission according to claim 12 wherein the CD comprises a three branch differential gear.

14. A transmission according to claim 13 wherein the CD comprises a "parallel axis epicyclic gear set", a "cross-axis epicyclic gear set", a "sun wheel compound parallel axis epicylic gear set", a "twin annulus compound parallel axis epicyclic gear set", or a "spur gear epicyclic gear set".

15. A transmission according to claim 1 or claim 2 wherein the second element of the FVT is connected to the third element of the CD by a direct drive connecting means and the CD has a fourth element and the third and fourth elements are alternately connectable to the first drive member of the drive transmission.

16. A transmission according to claim 15 wherein the CD comprises a four-branch differential comprising a first stage summing gear set and a second stage summing gear set.

17. A transmission according to claim 16 wherein the first stage summing gear set comprises a "parallel axis epicyclic gear set", or a "spur gear epicyclic gear set", and the second stage comprises a "parallel axis epicyclic gear set" or a "cross-axis

epicyclic gear set" or a "sun wheel compound epicyclic gear set", or a "twin annulus compound epicyclic gear set", or a "spur gear epicyclic gear set".

18. A transmission according to claim 15 wherein the CD comprises an "annulus, single planet and twin sun gear epicyclic gear set".

19. A transmission according to claim 18 wherein the planet gears have a first meshing part in mesh with the first sun gear and a second meshing part in mesh with the annulus and the second sun gear, the first and second meshing parts being of different diameter.

20. A transmission according to claim 19 wherein the first meshing part is of greater diameter than the second meshing part.

21. A transmission according to claim 15 wherein the CD comprises a differential according to any one of claims 25 to 33.

22. A transmission according to any one of the preceding claims wherein the FVT is a mechanical continuously variable transmission.

23. A transmission according to claim 22 wherein the FVT comprises a pair of split pulleys having variable spacing cheeks, drivingly interconnected by a continuous loop and in which the radius at which the belt drivingly engages the split pulleys is continuously adjustable by varying the spacing between the cheeks of the split pulleys, or a toroidal disk drive type comprising two disks each with a toroidal working surface engageable by a roller, the axis of rotation of the roller being adjustable to vary the radial positions at which the roller engages the toroidal surfaces.

24. A transmission substantially as hereinbefore described with reference to Fig. 1, or Fig. 2, or Fig. 3, or Figs. 4 to 5a, or Figs. 6 to 7a, or Figs. 8 and 9, or Fig.

10, or Fig. 11, or Fig. 12, or Fig. 13, or Fig. 14, or Fig. 15, or Figs. 16 and 17, or Figs. 18 and 19, or Fig. 20, or Fig. 21, or Fig. 22.

25. A controllerable differential, comprising

a carrier, acting as a first element,

a plurality of planet gears, each planet gear having first, second and third meshing parts of different diameter,

the carrier supporting the planet gears,

an annulus acting as a second element, in mesh with said first meshing part,

a first sun gear, acting as a third element, in mesh with said second meshing part, and

a second sun gear, acting as a fourth element, in mesh with said third meshing part.

26. A differential according to claim 25 wherein the second meshing part is of greatest diameter and the third meshing part of smallest diameter.

27. A differential according to claim 25 or claim 26 wherein the first meshing part is disposed between the second and third meshing parts.

28. A differential according to any one of claims 25 to 27 wherein the fourth element comprises a hollow shaft surrounding the third element and disposed within the second element, said second, third and fourth elements are coaxial and extend from one side of the gear set, whilst the first element extends from the opposite side of the gear set coaxial with said second, third and fourth elements.

29. A controllable differential comprising

a carrier, acting as a first element,

a plurality of first planet gears, each first planet gear having first and second meshing parts of different diameter,

a plurality of second planet gears,

the carrier supporting the planet gears,

a first sun gear, acting as a second element in mesh with the second planet gears,

a second sun gear, acting as a third element, in mesh with said first meshing part of the first planet gears,

a third sun gear, acting as a fourth element, in mesh with said second meshing part of the first planet gears, and

said second meshing part of the first planet gears being in mesh with a respective second planet gear.

30. A differential according to claim 29 wherein the first meshing part is of larger diameter than the second meshing part.

31. A differential according to claim 29 or claim 30 wherein the fourth element comprises a hollow shaft coaxial with said first element and disposed within said second element.

32. A differential according to any one of claims 29 to 31 wherein the second, third and fourth elements are coaxial and project from one side of the transmission whilst the first element projects on the opposite side of the transmission coaxial with said second, third and fourth elements.

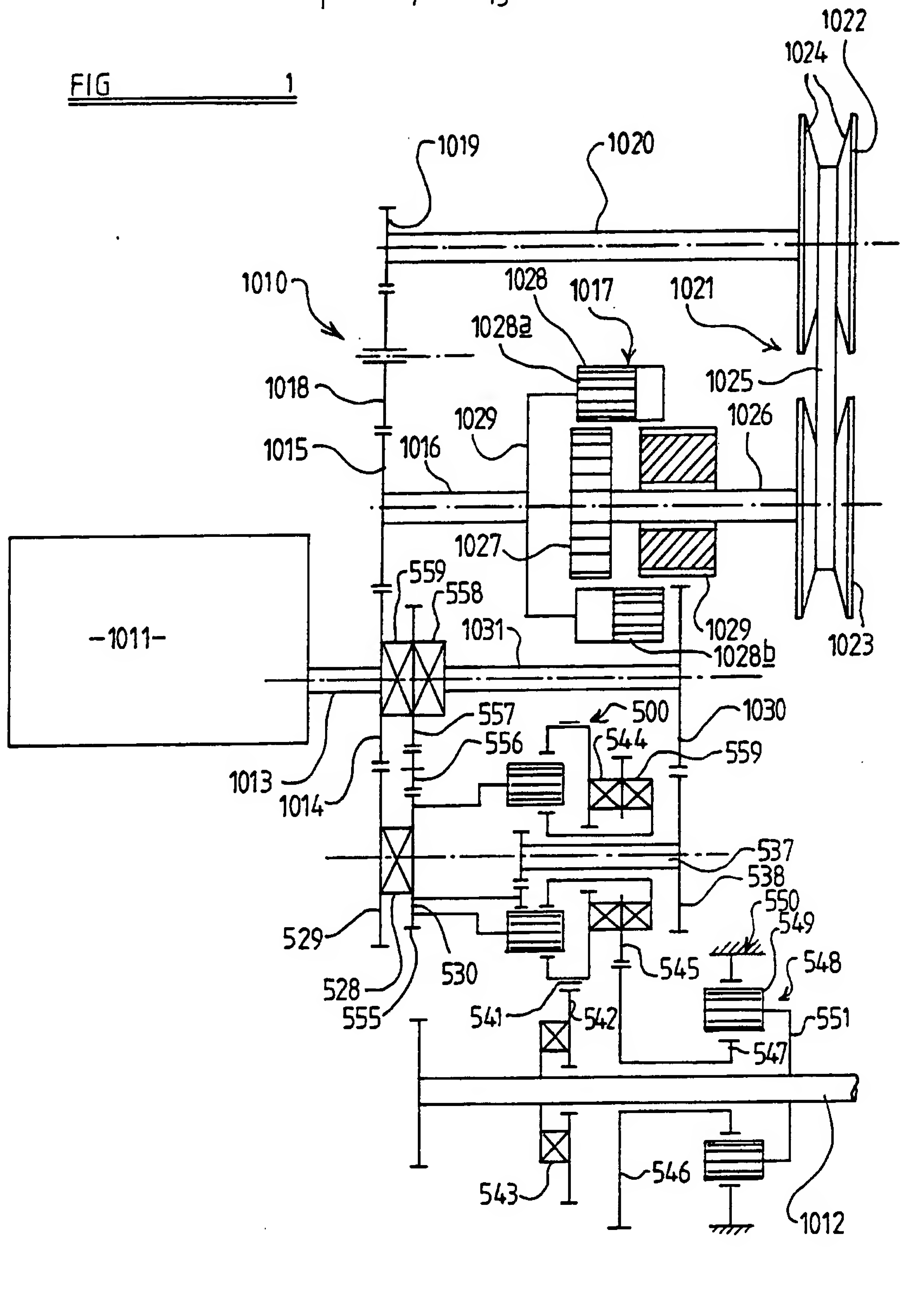
33. A differential substantially as hereinbefore described with reference of Figs. 16 and 17 or Figs. 18 and 19.

34. A transmission according to any one of claims 1 to 24 when provided in a vehicle with the driven member of the transmission being connectable to provide motive power for the vehicle and/or provide a power input to apparatus of the vehicle.

35. A transmission according to claim 34 wherein the vehicle is a construction machine provided with an earth moving appliance.

36. Any novel feature or novel combination of features described herein and/or in the accompanying drawings.

FIG 1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558
1029
1031
1028b
1023
-1011-
557
500
1030
544
556
559
1013
1014
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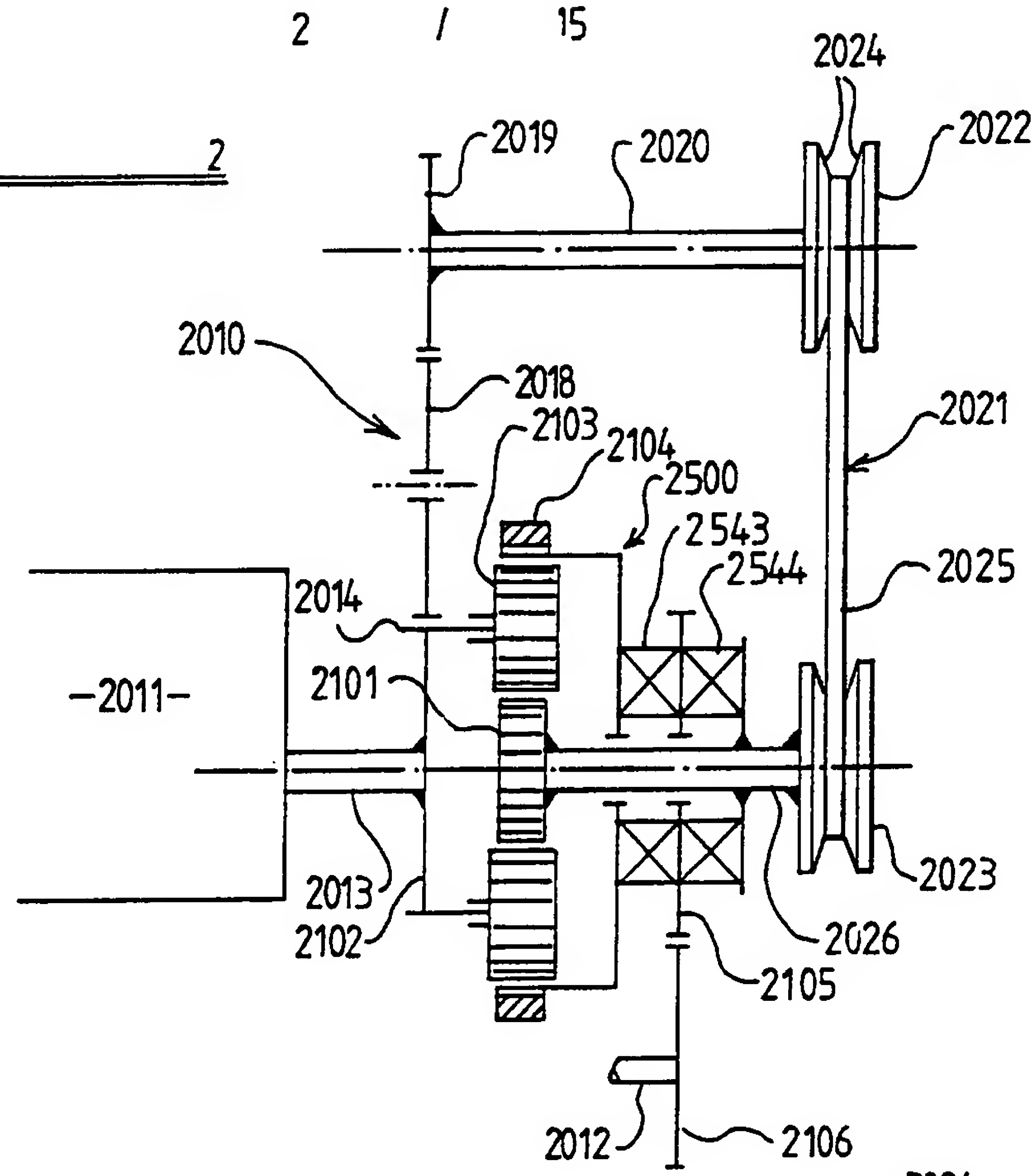
1012

FIG 2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2023
2026
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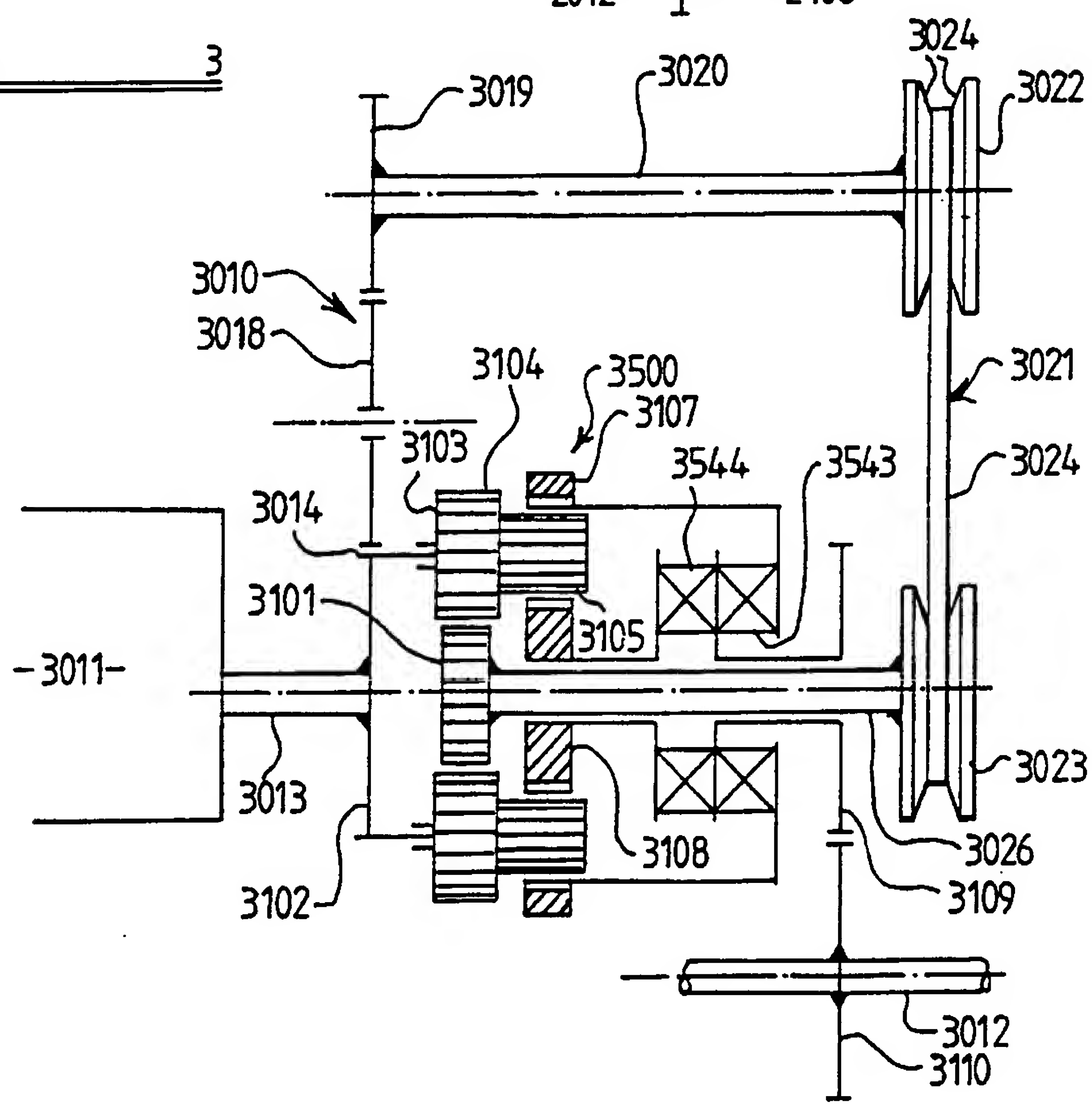
2012
2106

FIG 3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3012
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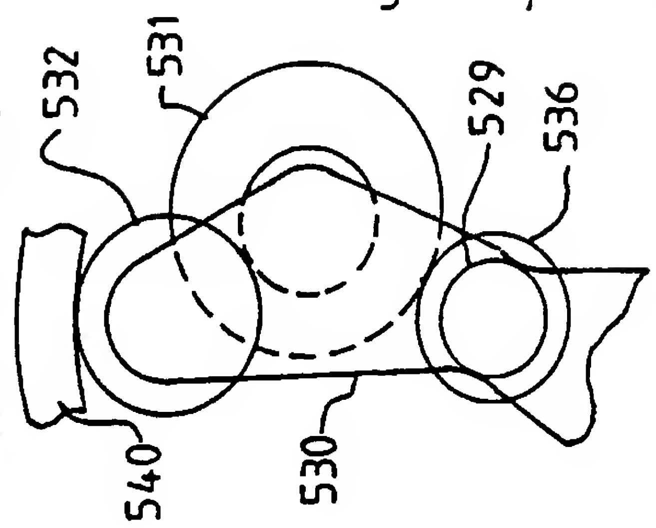


FIG 5a

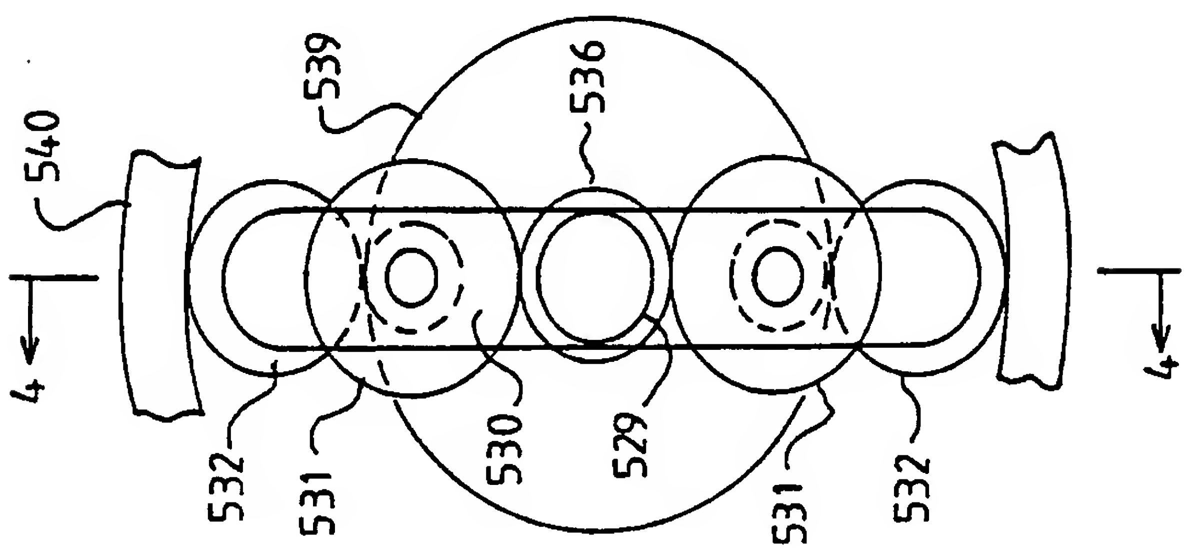


FIG 5

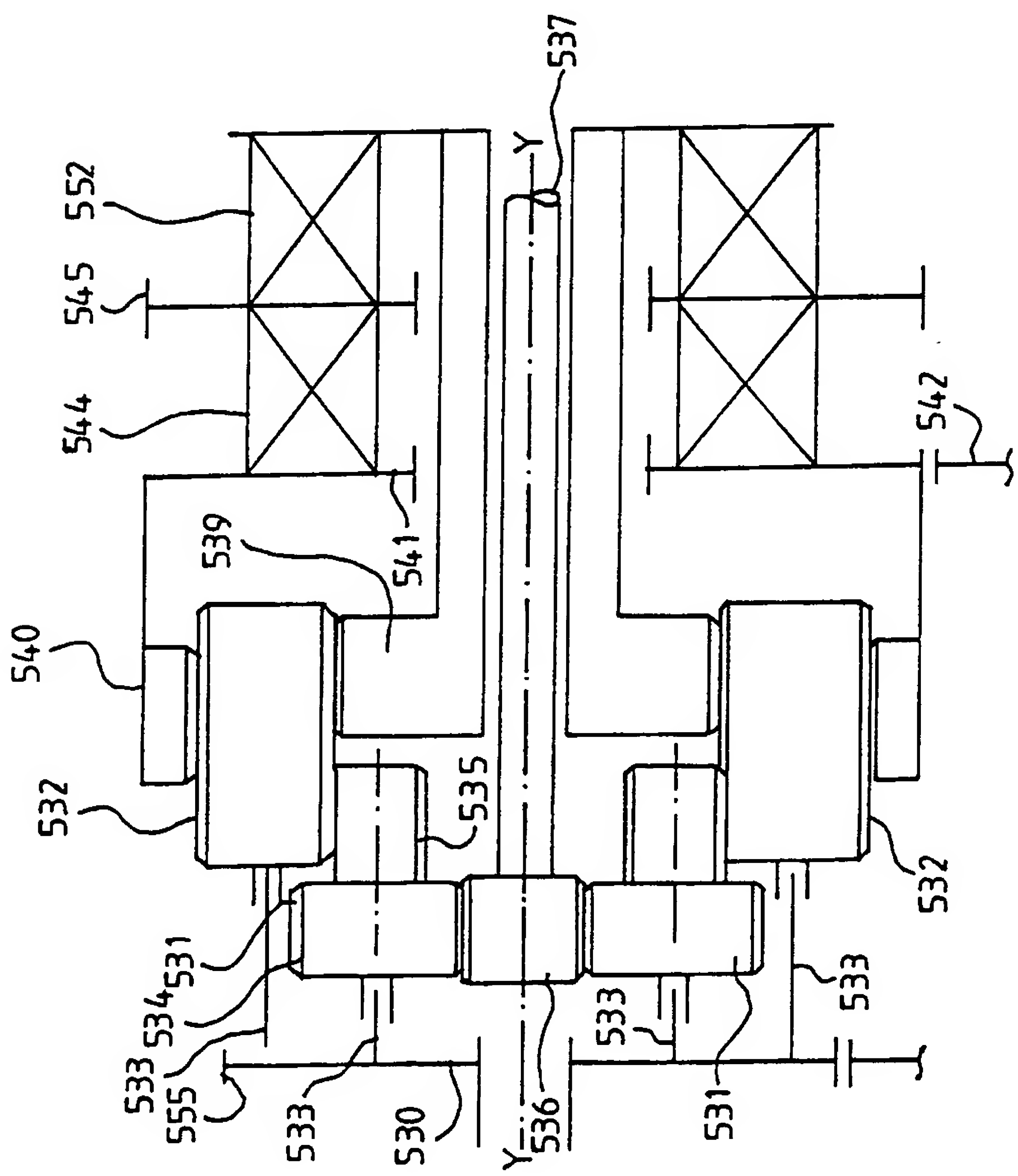


FIG 4

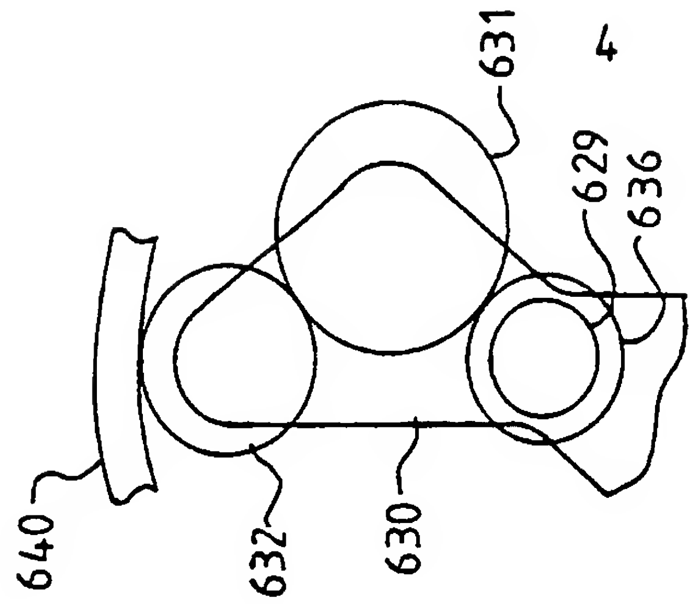


FIG 7a

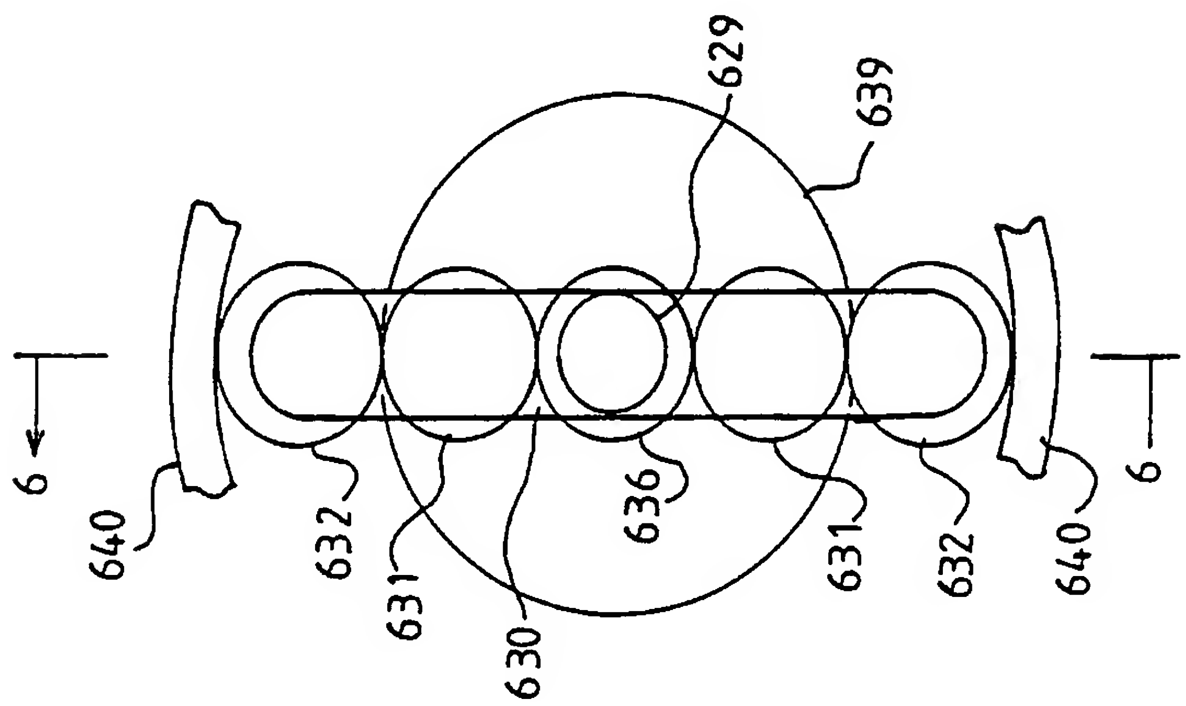


FIG 7

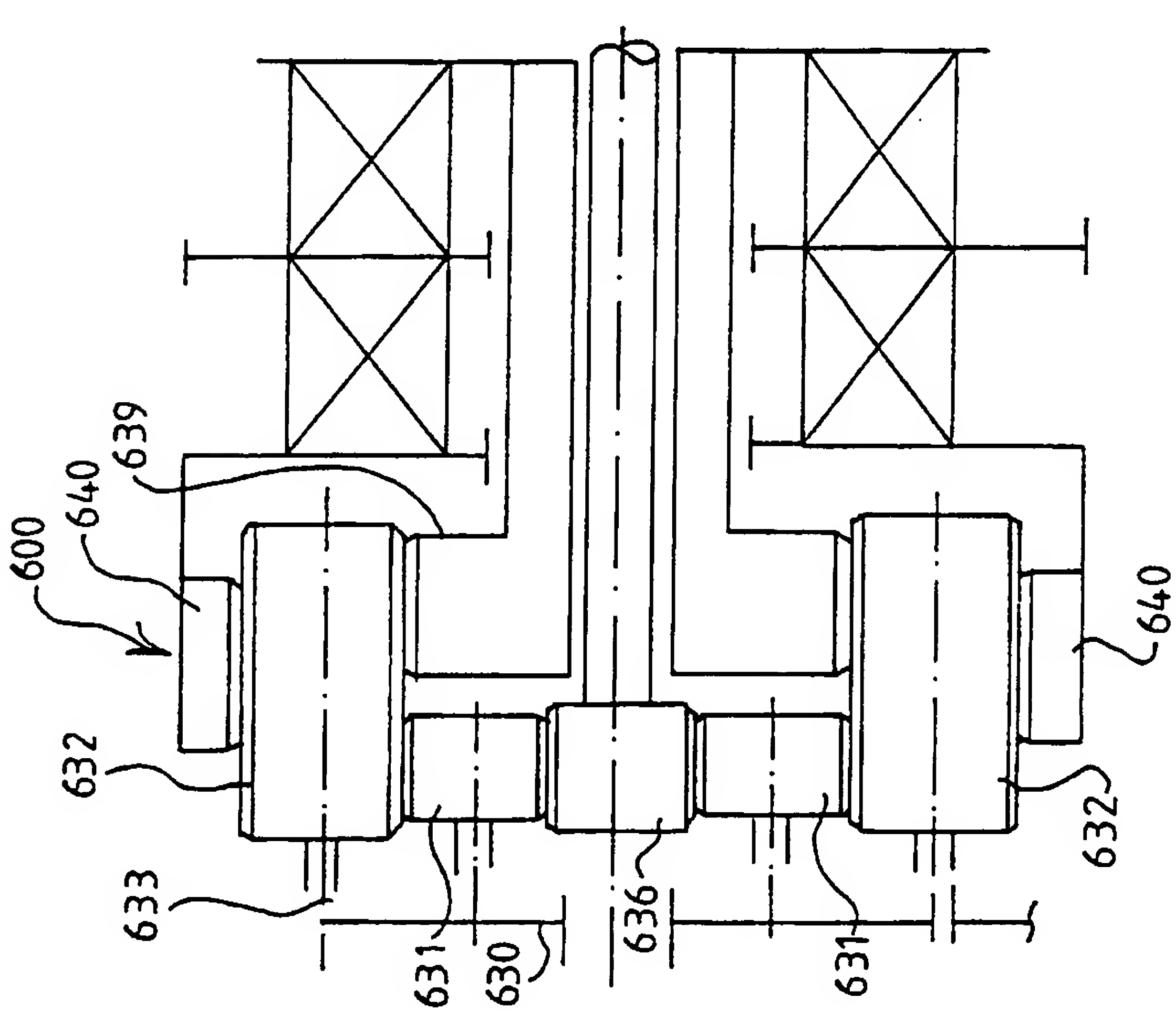
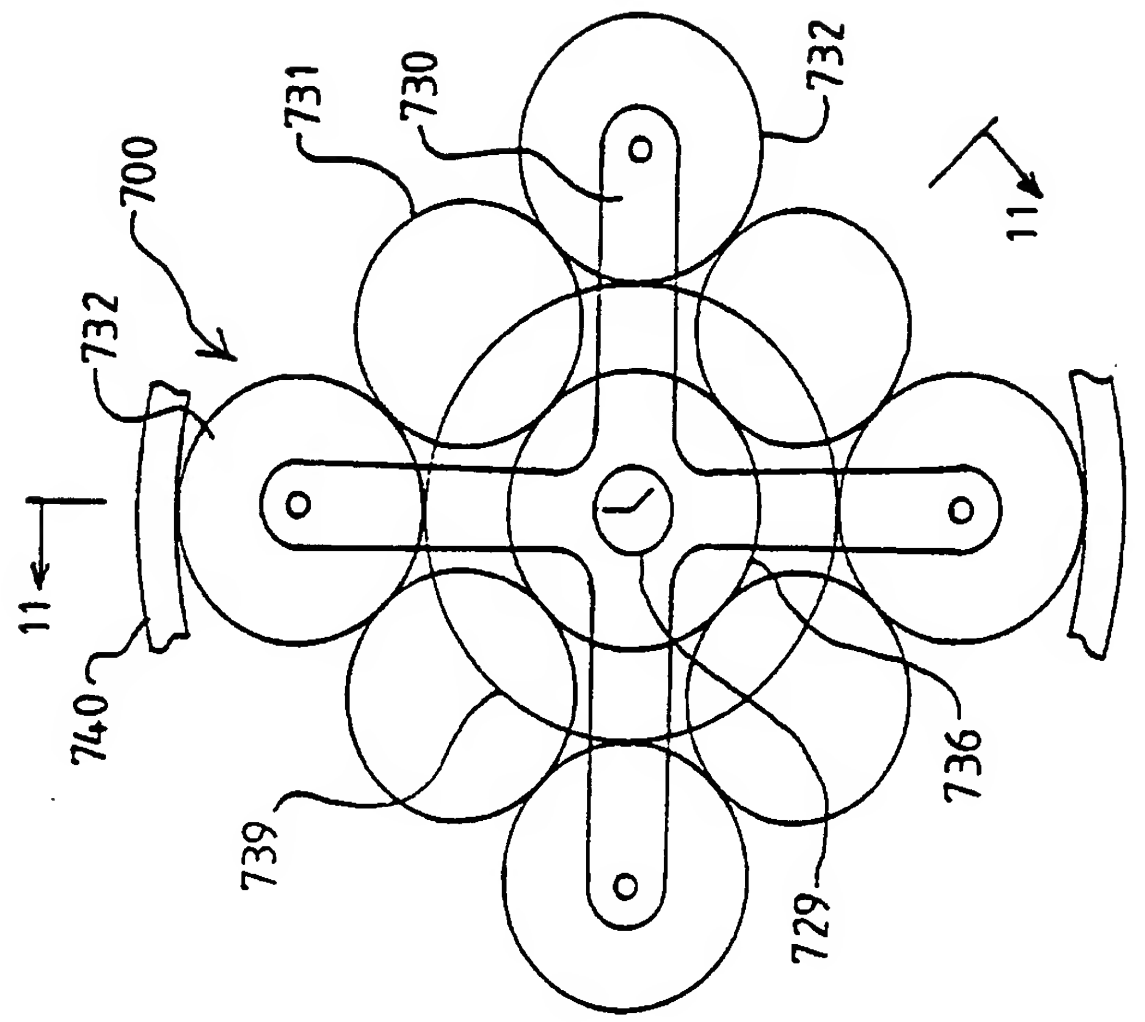


FIG 6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732
731
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11
11
740
739
729
736

FIG 9

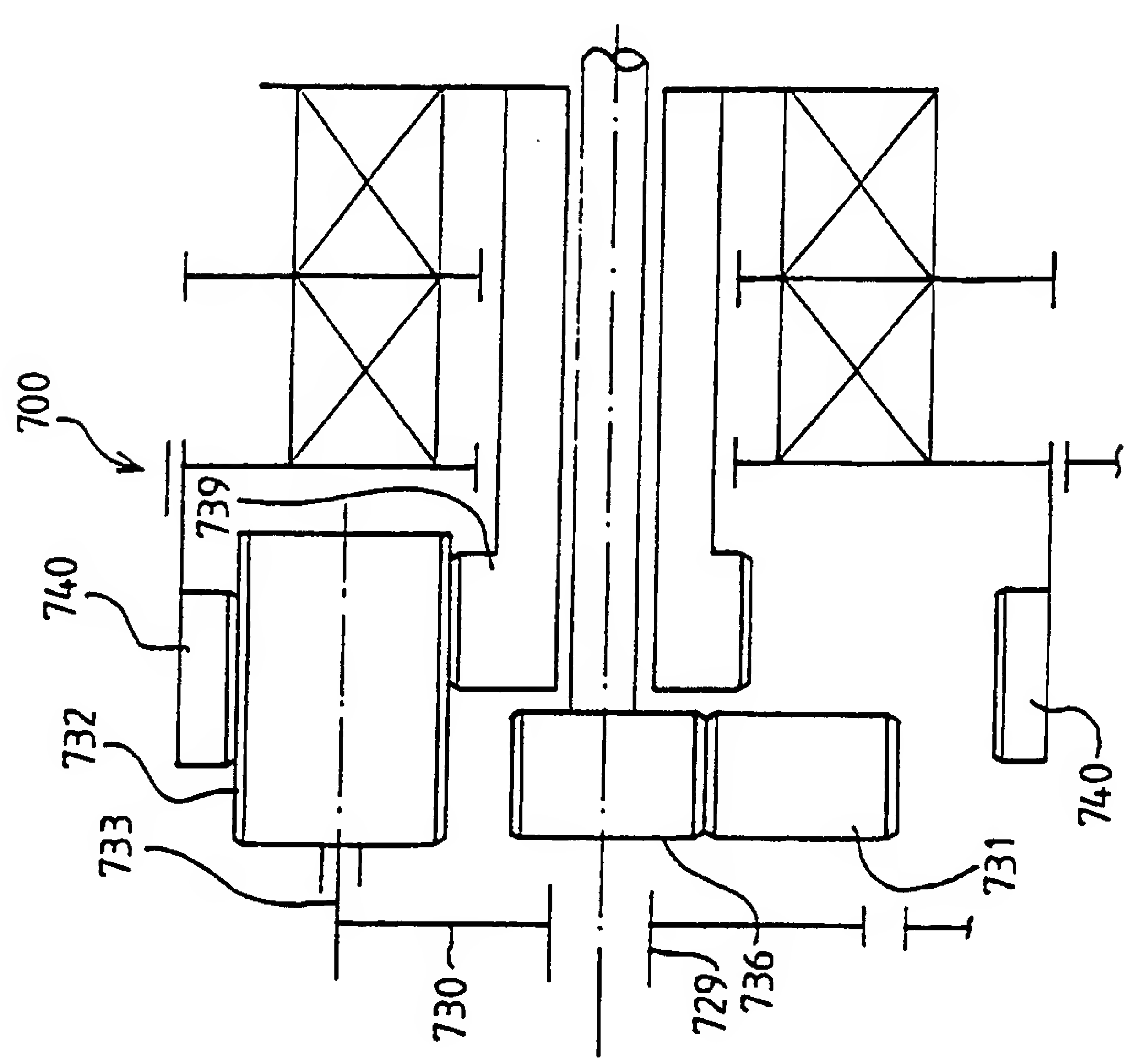
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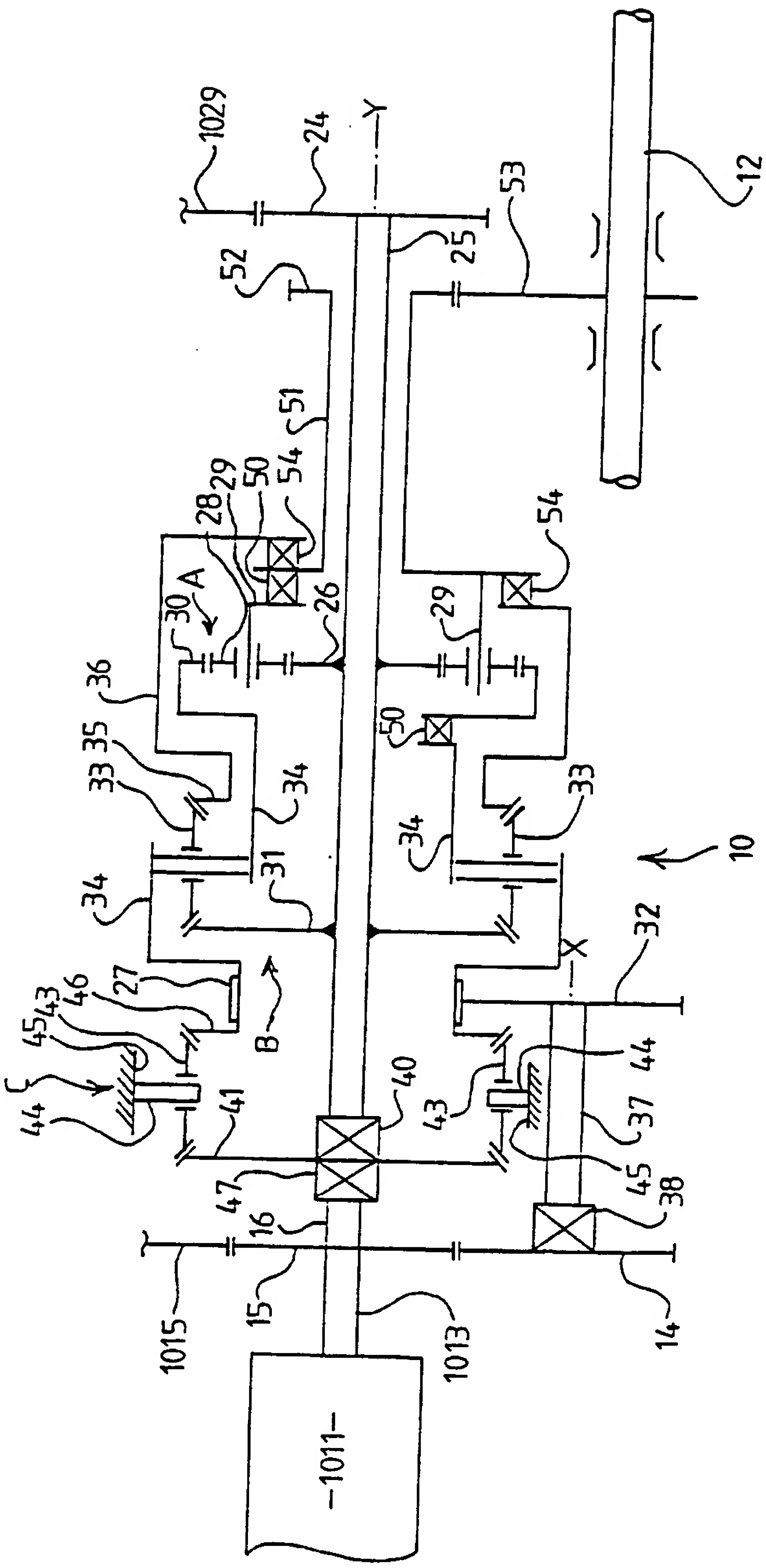
FIG 8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A
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54
29
33
34
10
32
X
27
46
43
45
C
44
B
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41
47
16
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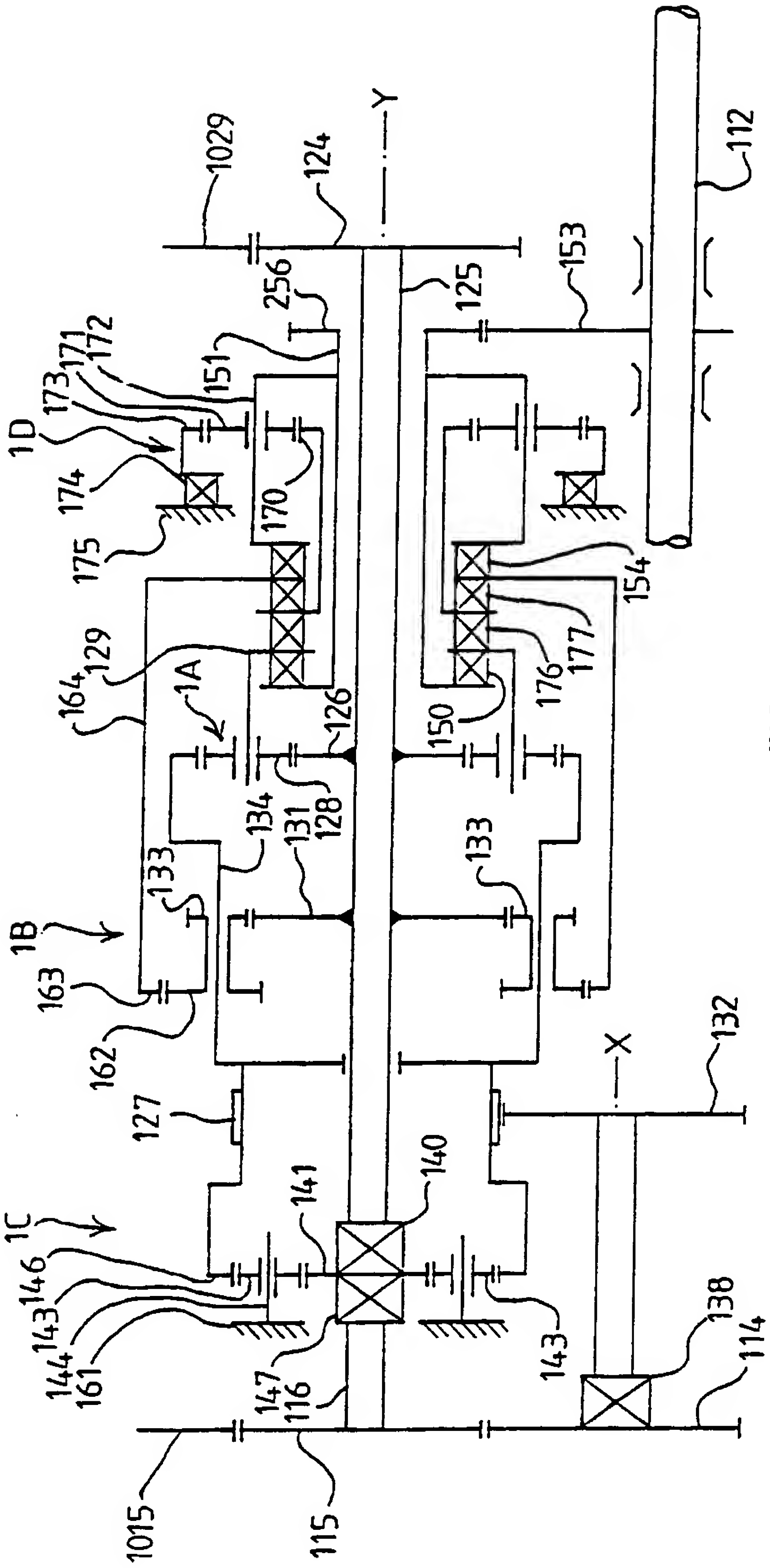
1015
1013
14
38
37
44
43
45
1011

FIG 10



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153
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171
172
173
1D
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1A
126
134
131
128
133
1B
163
162
X
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140
141
1C
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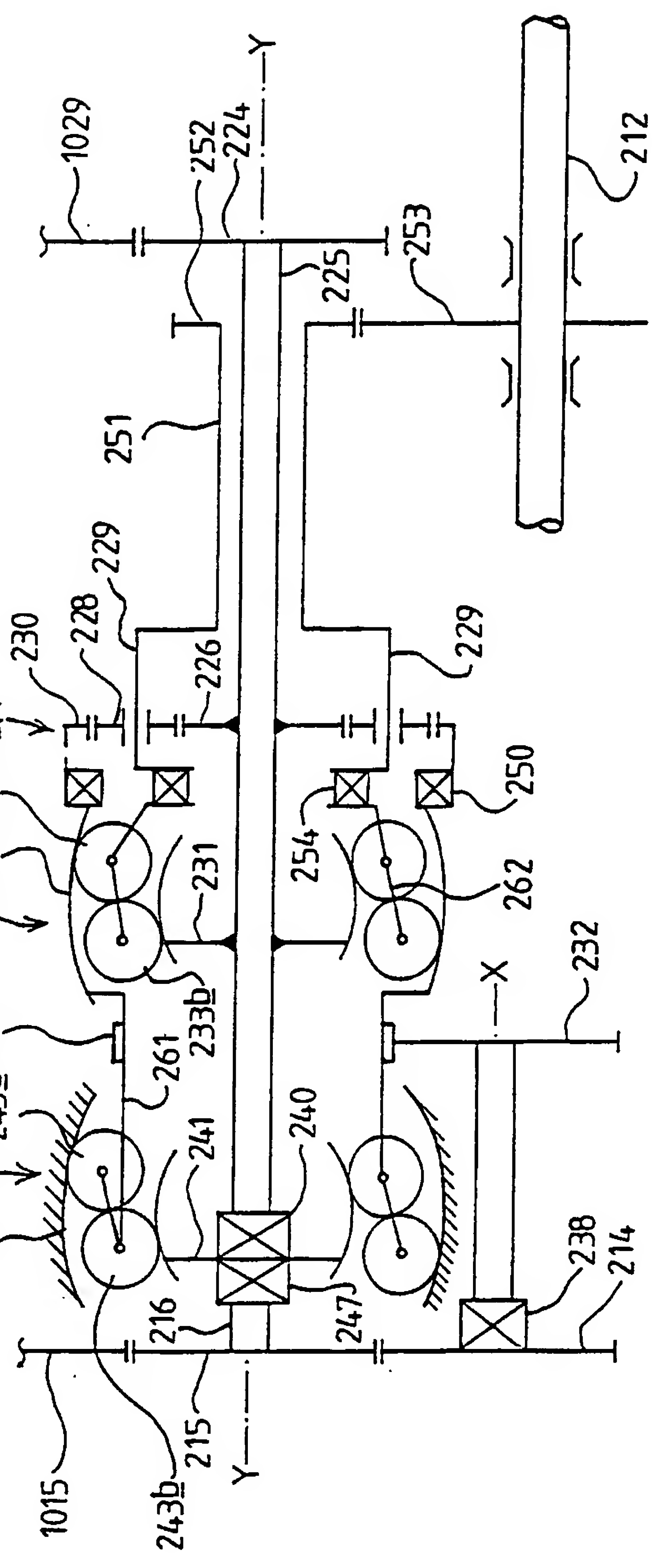
144
161
147
116
138
114
1015
115

FIG 11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216
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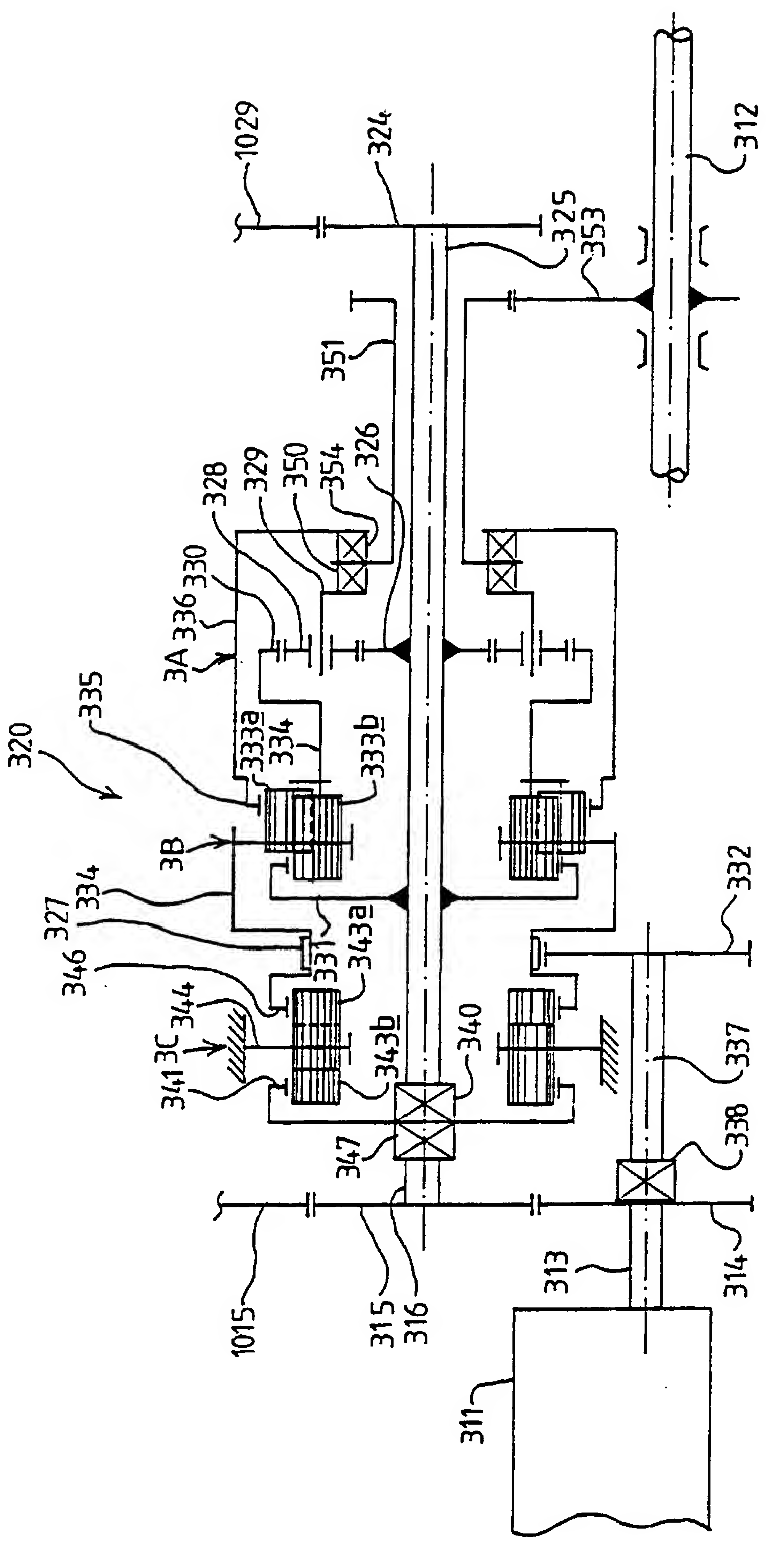
1015
243b
215
Y

FIG 12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334
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1015
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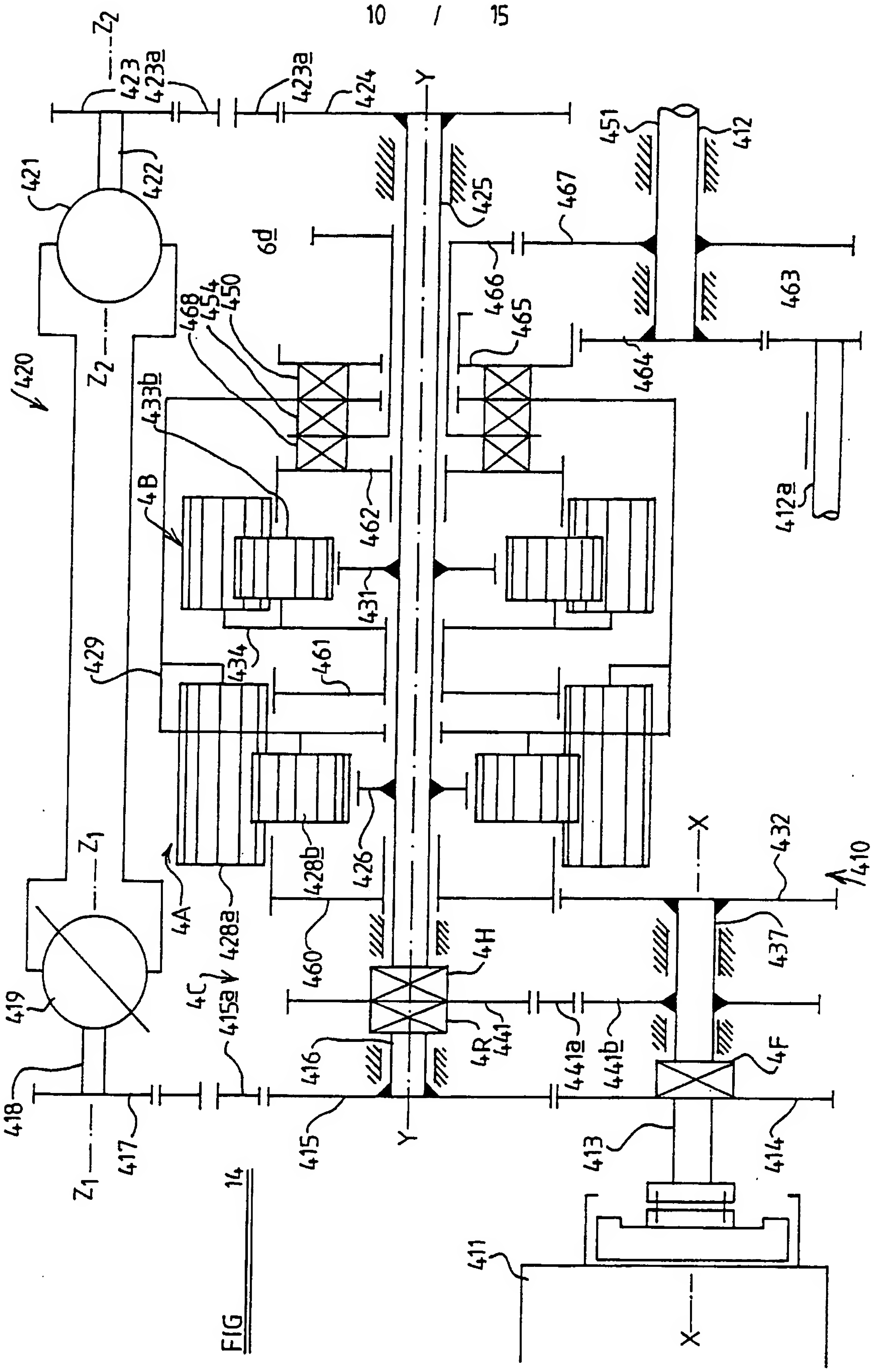
FIG 13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433b
4B
462
412a
431
434
461
429
Z1
X
432
410
4A
428a
428b
426
460
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411

FIG 14

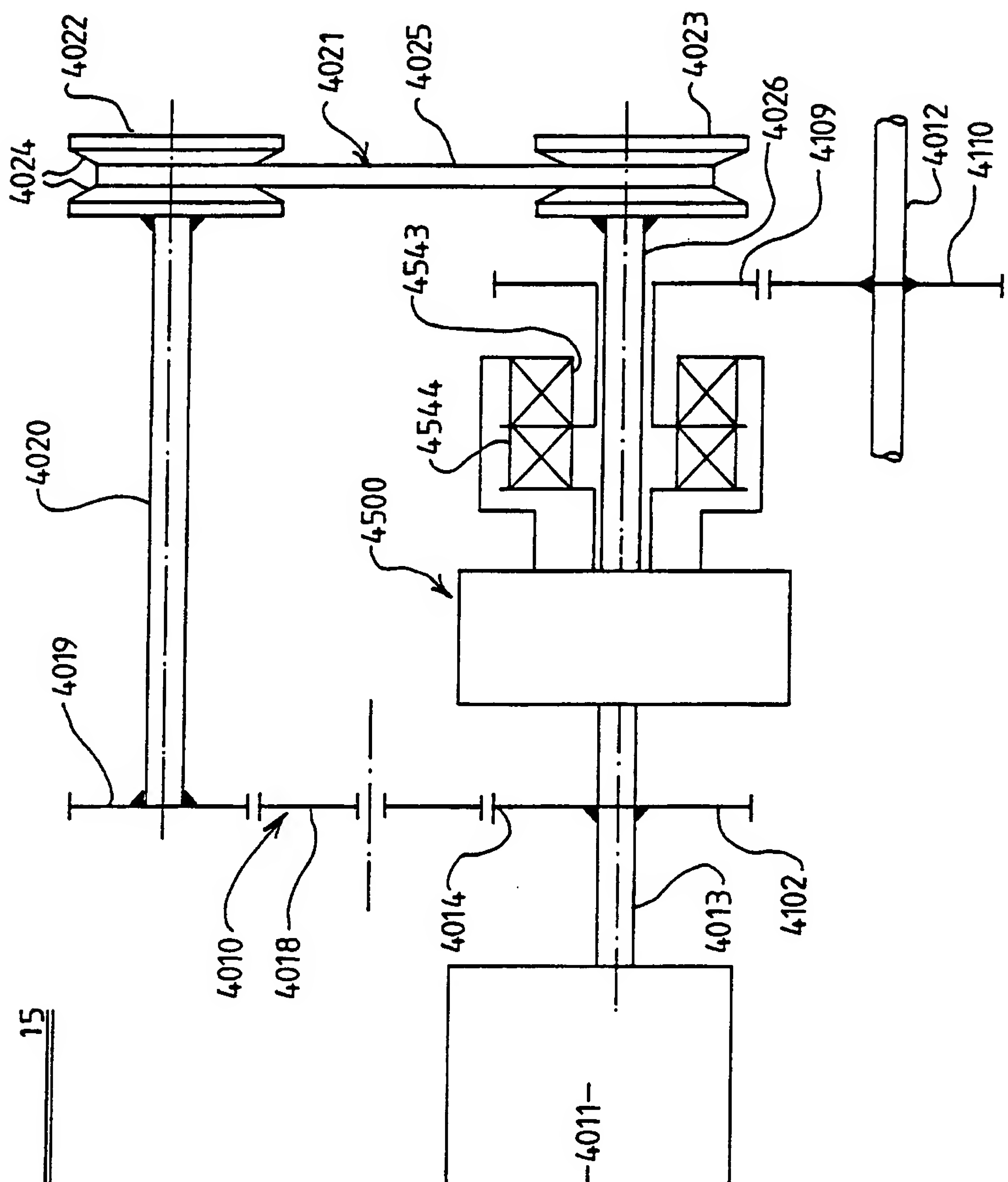
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FIG 15

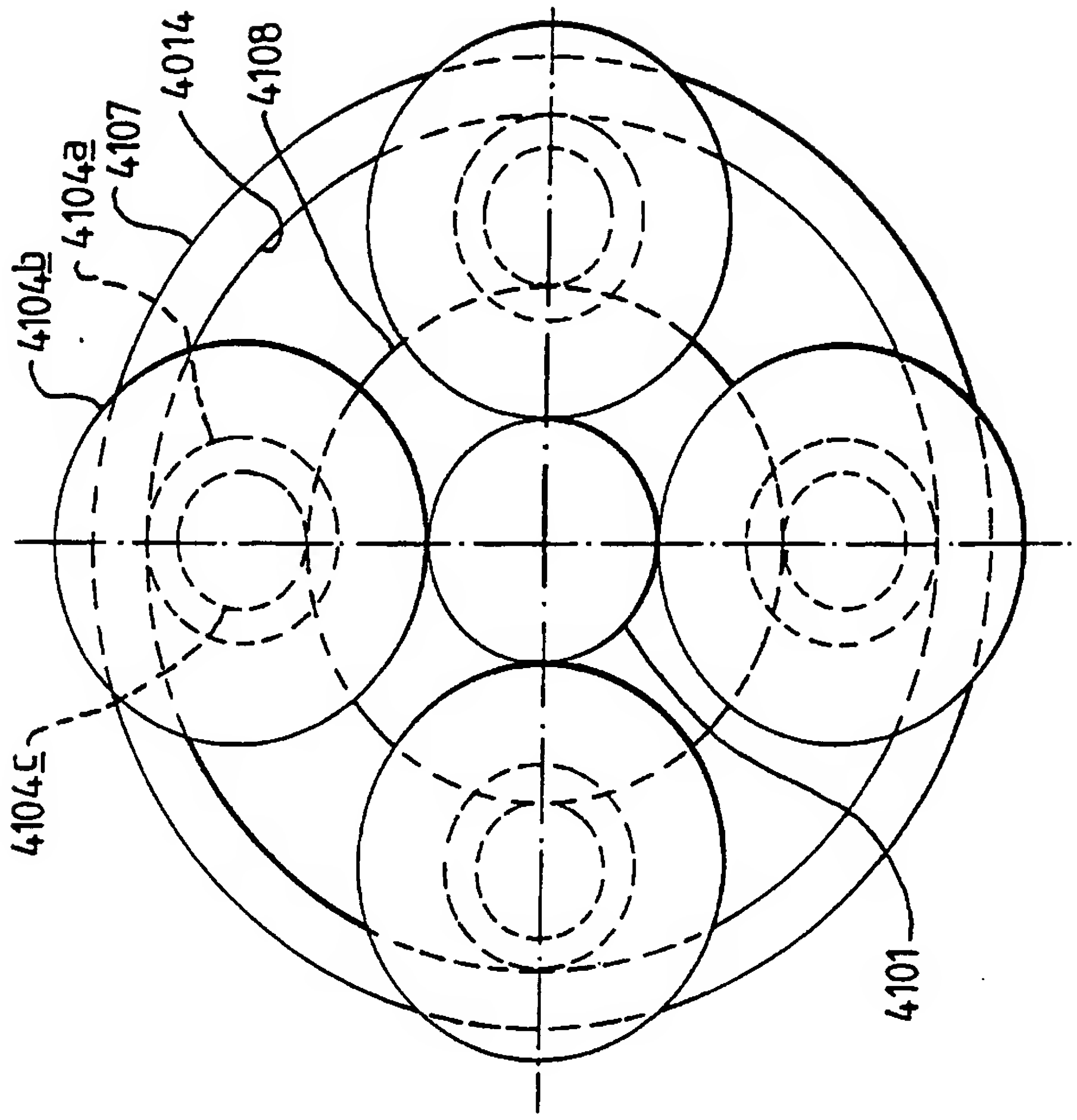
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FIG 17

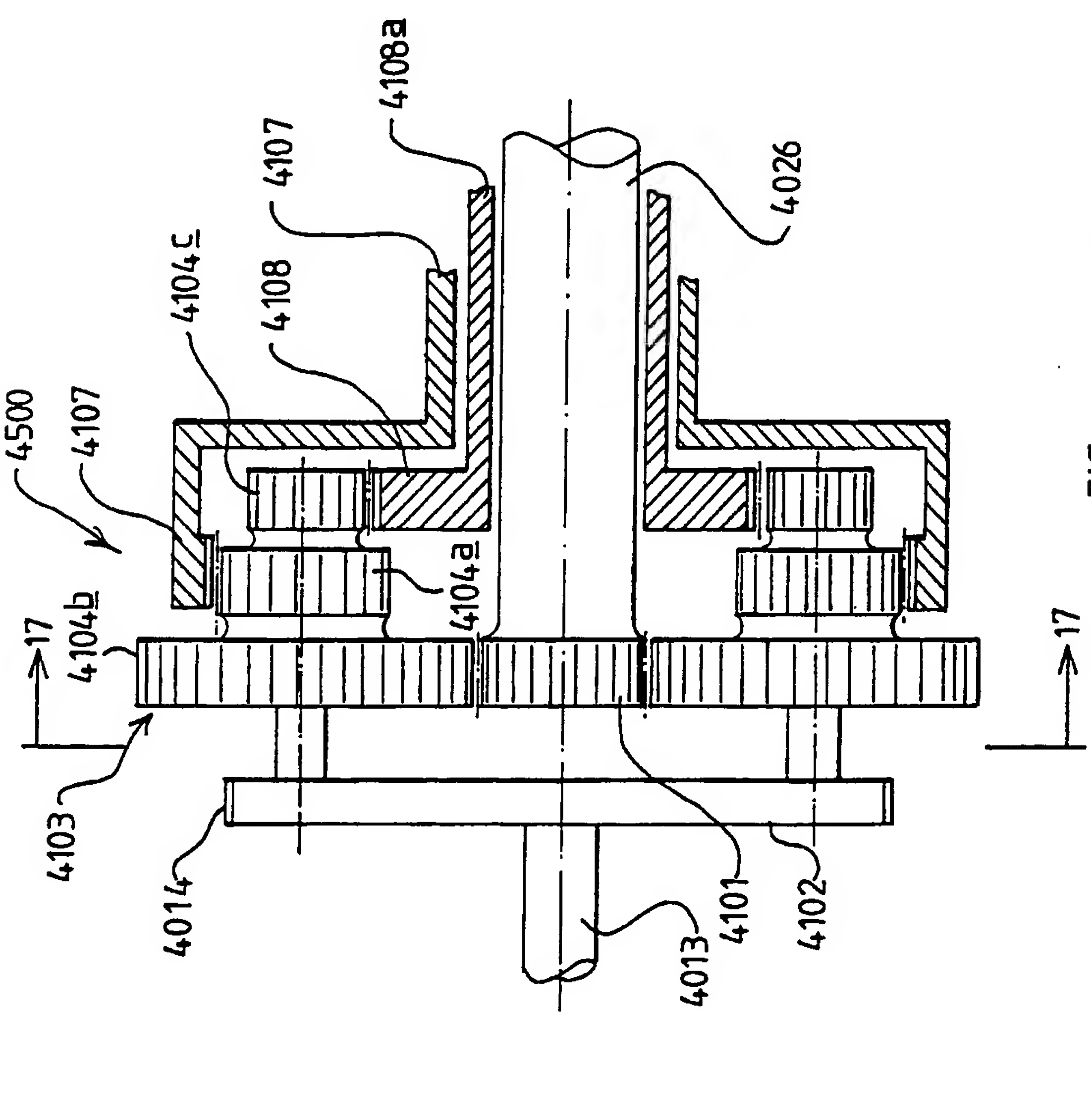
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FIG 16

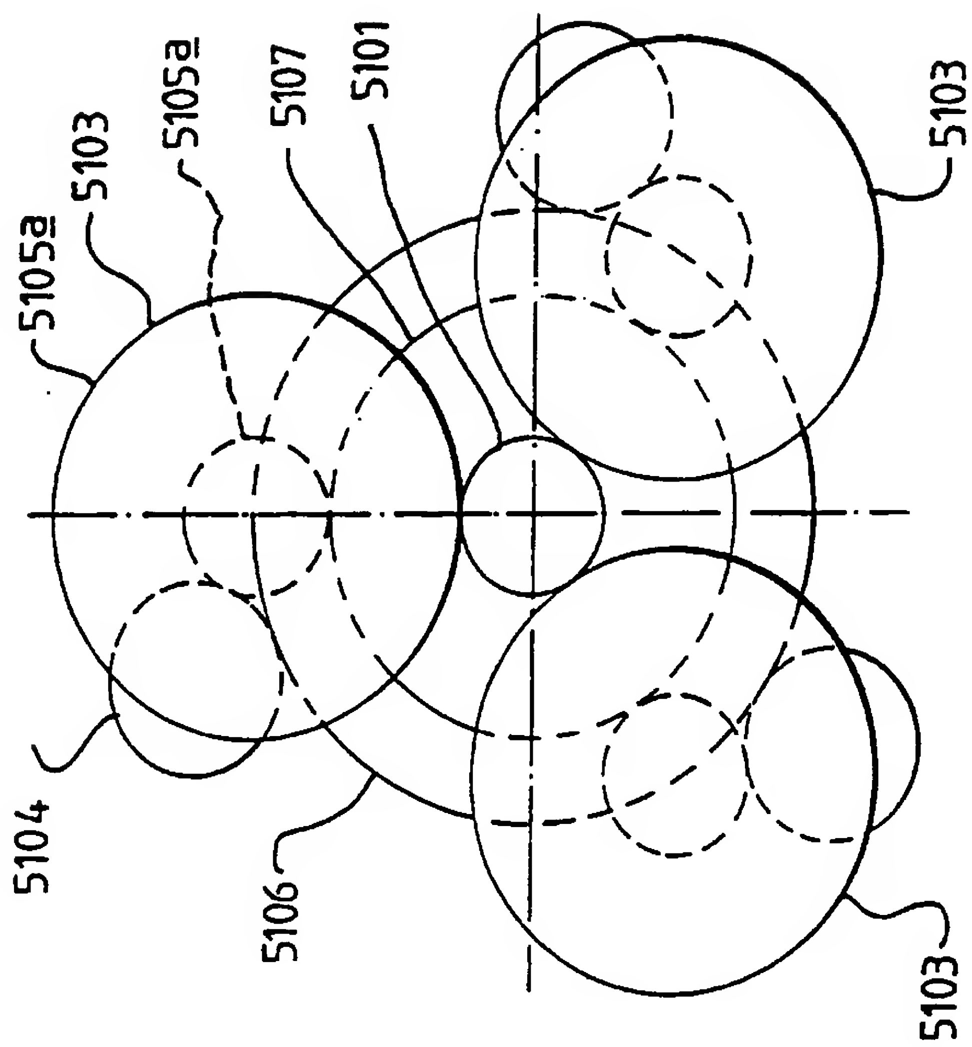
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FIG 19

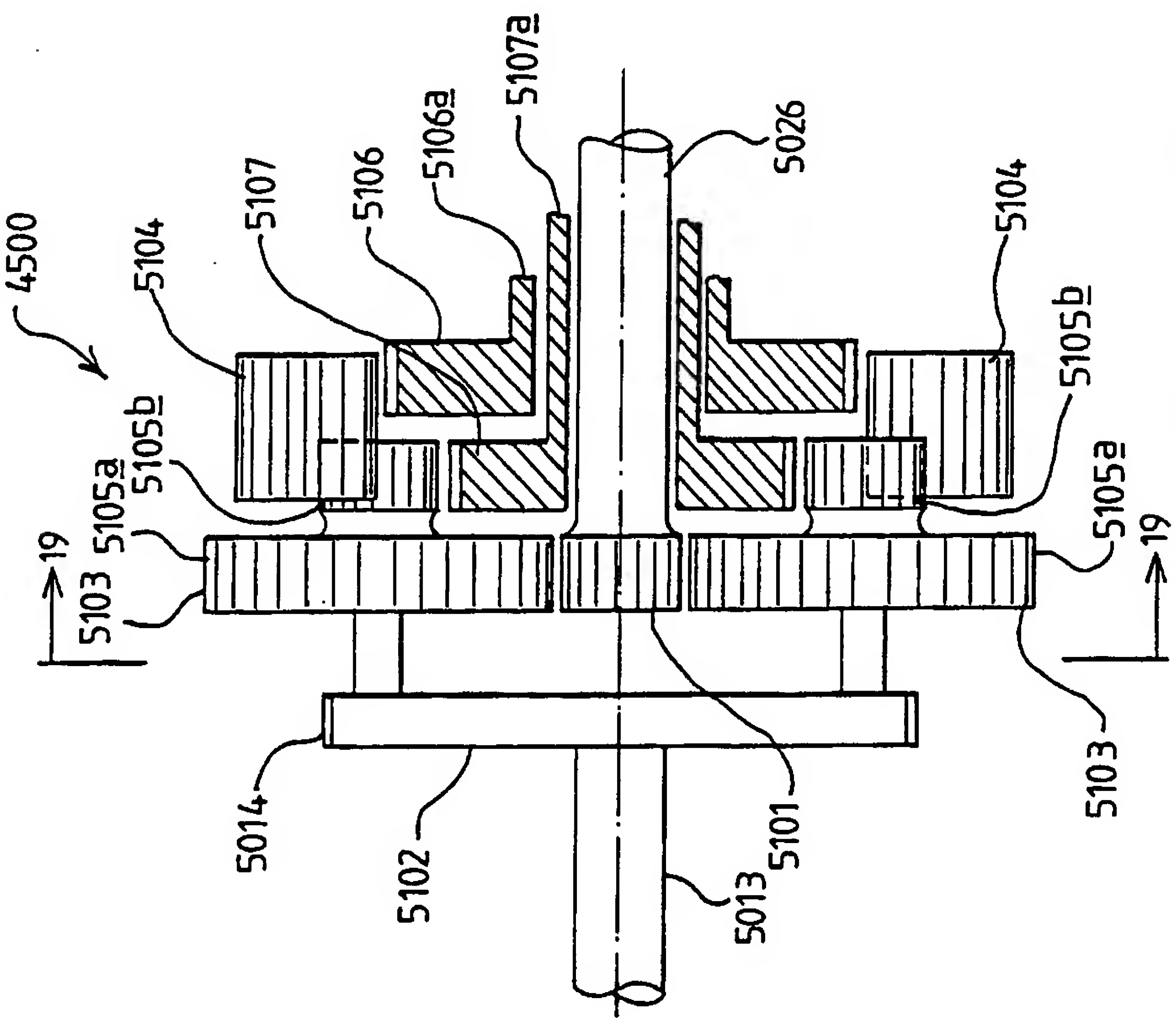
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FIG 18

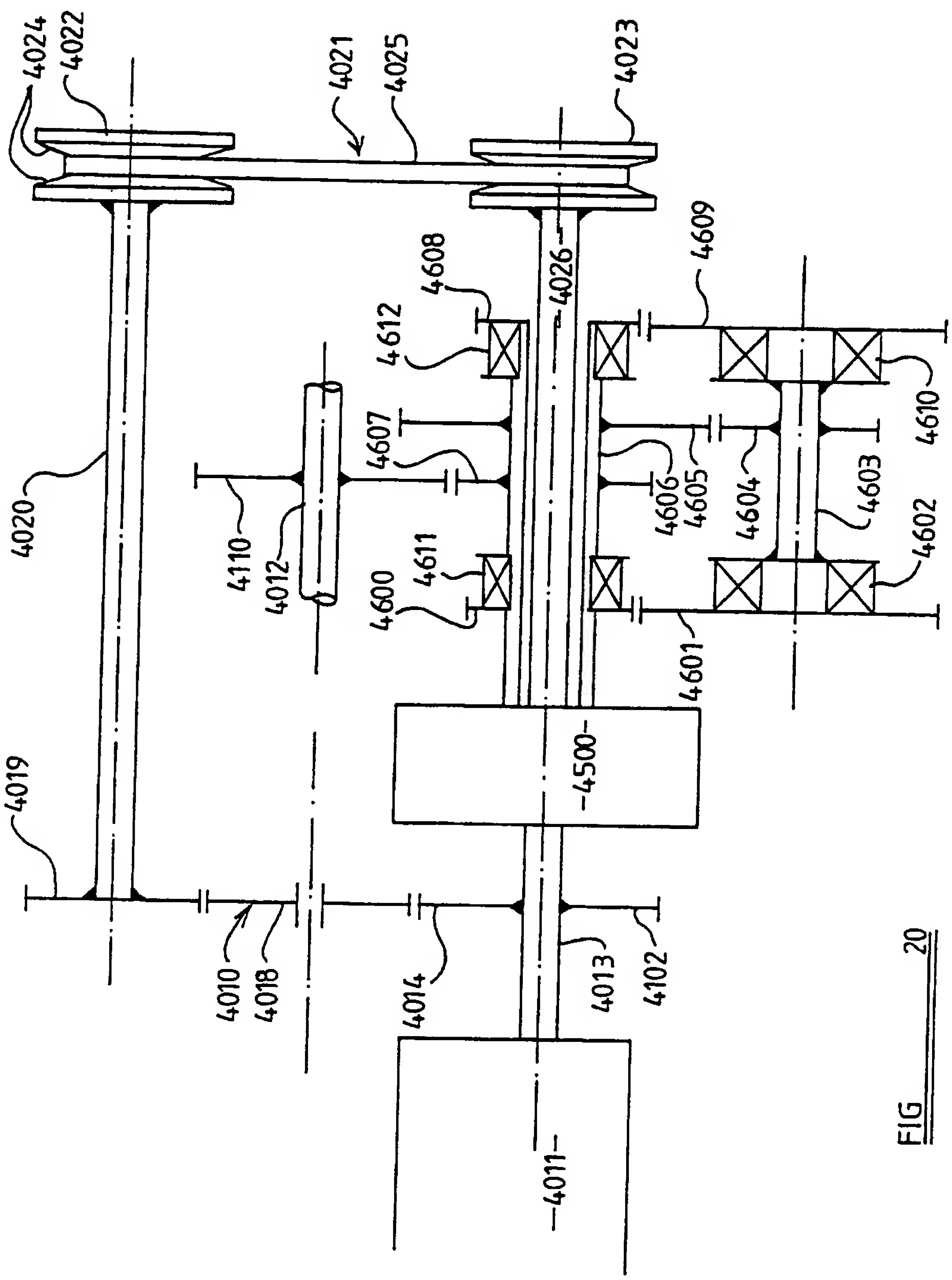
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FIG 20

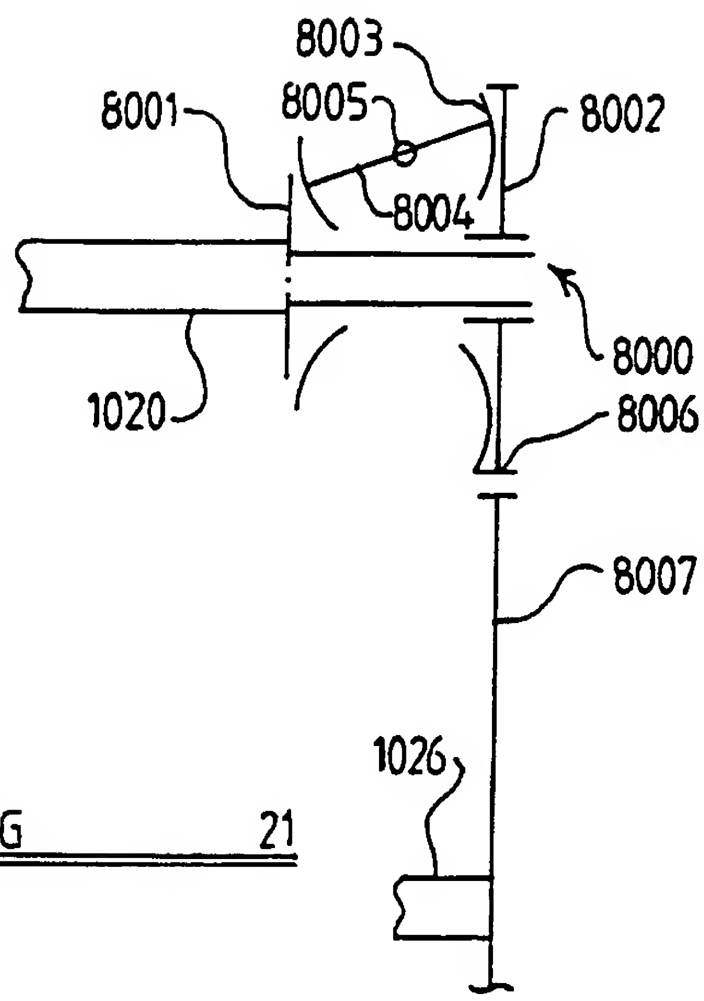

FIG 21

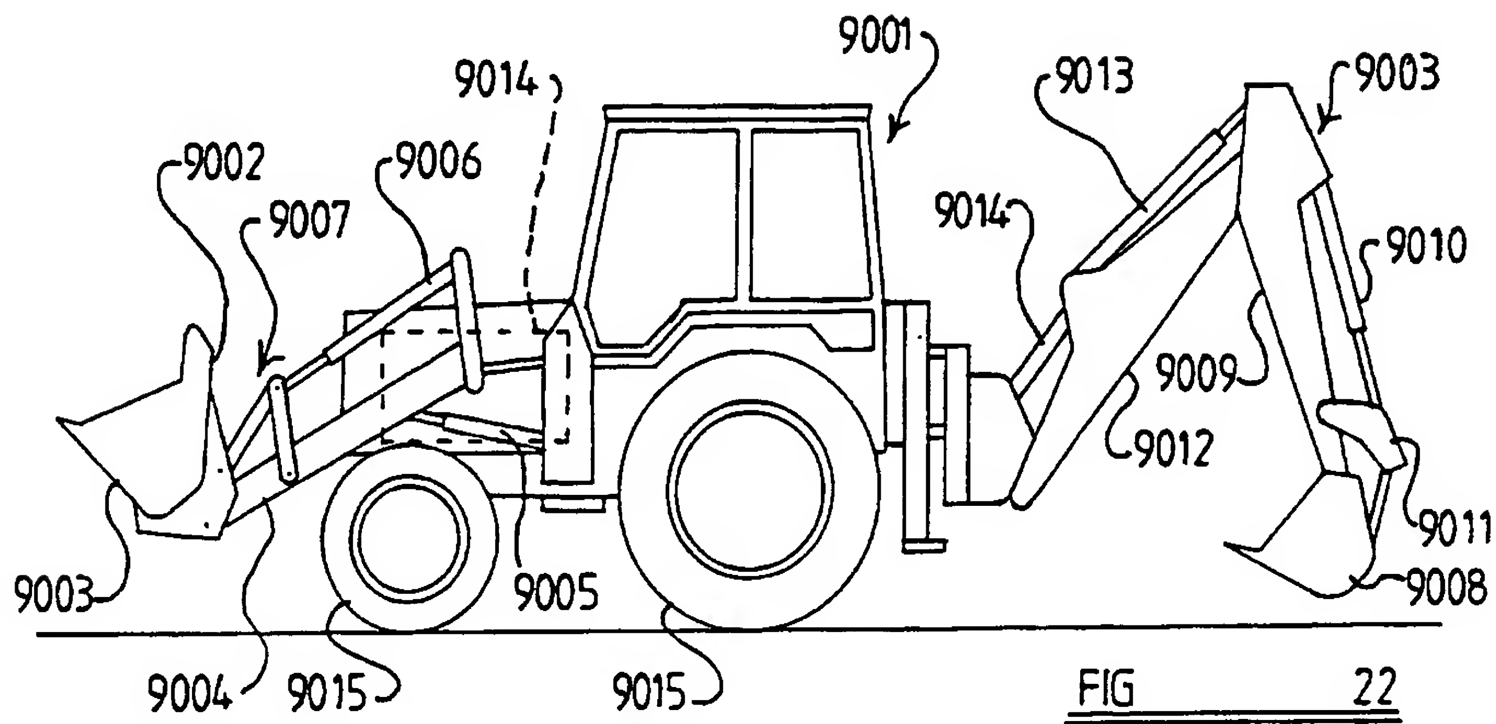

FIG 22

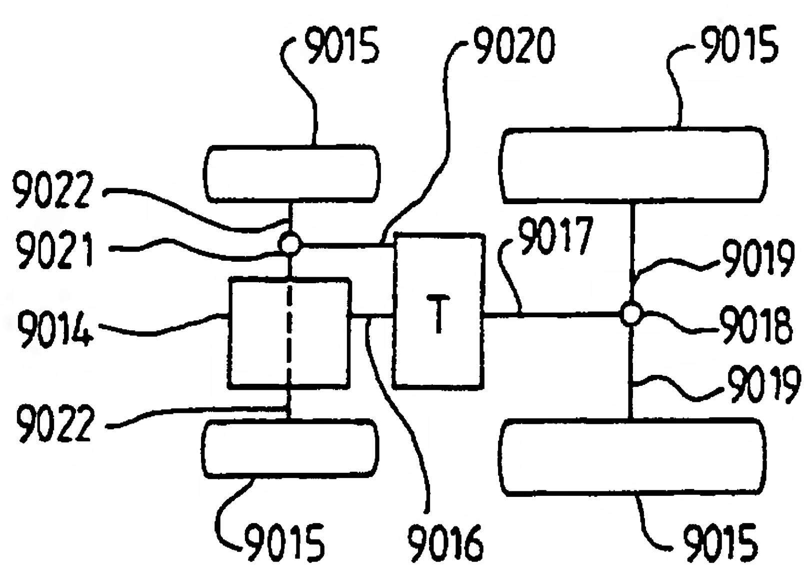

FIG 23